SCIENCE AT YOUR SERVICE

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by

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CONTENTS

Chapter		Page
	PREFACE	7
1	SCIENCE AND THE HOUSE by Julian S. Huxley, F.R.S.	11
2	THE SCIENCE OF BUILDING by Sir Edward Appleton, K.C.B., F.R.S., and Sir George Burt	18
3	PLASTICS by Sir Lawrence Bragg, F.R.S.	26
4	CLOTHING AND FABRICS by Professor J. B. Speakman, D.Sc.	33
5	EXPLOSIVES by Professor John Read, F.R.S.	41
6	SOUNDING THE EARTH'S CRUST by Dr. A. O. Rankine, O.B.E., F.R.S.	49
7	OUR WEATHER by Sir Nelson Johnson, K.C.B.	58
8	THE HOUSEWIFE AND THE FISHERIES by Michael Graham	64
9	SAVING LIFE AT SEA by Dr. Albert Parker and H. S. Humphreys	72
10	SCIENCE AND SHIP DESIGN by J. L. Kent	80
11	THE TUNNEL BUILDERS by G. L. Groves, B.Sc., M.Inst.C.E.	87
12	SCIENCE IN NATIONAL LIFE by E. C. Bullard, F.R.S.	95

ILLUSTRATIONS

Facing page

Surface Structure of Wool, Magnification 800, and Human Hair near the root, Magnification 500 — 48

Berthold Schwarz in his Laboratory — 49

Showing the Alfred Yarrow Tank with the Carriage Spanning the Waterway, and Models — 80

New Fire-resistant Steel Life-boat for Tankers, Showing Water Sprays being Tested before the Fire Test — 81

The Life-boat Hidden in Smoke and Flames During the Fire Tests — 81

PREFACE

This book contains twelve talks broadcast by the B.B.C. in their Home Service during the winter of 1943-44. The series was called "Science at Your Service," and its object was to show the influence of science on everyday life. Each speaker dealt with some subject of practical importance with which he was specially acquainted, such as textiles, fish, or tunnels. Each talked about the difficulties of providing what people need, and explained how some of these difficulties have been overcome, and how the rest are being tackled.

These talks show that not all science is remote and theoretical, but that much of it affects our daily lives. Each speaker is talking about a subject to which he has devoted a large part of his energies for many years; each is therefore an enthusiast, and paints a rosy picture describing the successes that have been achieved, and the prospect of further successes in the future. Up to a point this optimism is justified. The application of science can increase the wealth of the world; but when all these talks are put together, as in this book, I think that in some ways they give a false impression of the social effects of science. They are too much like the advertisement of a patent medicine; in fact, too good to be true. One gets the feeling that science is a universal cure for all human ills, that it will restore our export trade, raise our standard of living, and provide everyone with ninepence for fourpence.

It is important to bear in mind that science does not do all these things automatically. It is just as capable of pro-

viding guns as butter; it can as easily be used to kill men as mosquitoes.

During the past three hundred years we have discovered how to make Nature give us what we want. The technique consists in using past experience to formulate general principles which we call "Laws of Nature," and applying these to decide what will happen in the future. The essential point is that it is experience that led us to rely on these principles, not intuition, or supernatural powers, or philosophical ideas. There is absolutely nothing in this process that ensures that the results are good or desirable. It is simply a process for securing a specified end.

The moral of this seems to me to be that science can only produce worth-while practical results if the social system is so contrived that applied science is directed to worth-while aims. No matter how many excellent scientists there had been in Nazi Germany the standard of living of the people would not have been improved. The only results would have been to accelerate the preparations for war and to make it more deadly.

Owing to their successes in this war scientists are, at the moment, popular people in this country; and there is, I think, a tendency to swing right over from an attitude that regarded science as unimportant to one that regards it as a cure for all ills. I am afraid that our hopes are likely to be disappointed unless we are a good deal more certain of what we want science to do for us than we were before the war. Our resources will always be limited, and there will always be the problem of choosing in what direction we want to use our time and efforts. Do we want more houses, cleaner milk, more aeroplanes, television, or better hospitals? We cannot have everything we want, but by proper appli-

SCIENCE AND THE HOUSE

By JULIAN S. HUXLEY, F.R.S.

WHY should we need science to come butting in to our houses? Hasn't man been able without science to produce the most gracious and efficient homes? The answer is both yes and no.

It is true that a good Queen Anne house, for instance, is as attractive a place to live in as one could wish. But when it was built most of our population was still living in squalid hovels of insanitary if picturesque cottages. Indeed, throughout all history, most human beings have been badly or inadequately housed. Science is needed to help us remedy that.

A second reason is given by the particular situation in which we now find ourselves. The nineteenth century with its system of individualism and *laissez-faire* certainly produced wonderful progress in some directions, but in others its consequences were not so good. It produced the ugliest and dreariest as well as the biggest towns in history; new and larger slums; jerry-building; traffic chaos; ribbon development. The net result is so vast and so chaotic that nothing but drastic planning can possibly adjust it to real human and social needs; and planning, if it is to be any good, implies the use of scientific method.

The third reason is that in the long run science has something to say in every field of human life. As the house supplanted the hut and the primitive shelter, man gradually came to realize that he could, in his home, create an artificial environment for himself. In addition to the old needs of protection from heat and cold, rain and sun, and of security for person and property, humanity evolved new

needs which houses had to meet—the need for comfort and convenience; for privacy at one time and sociability at another; for spaciousness; for beauty. The house could and should be a machine for living—and as with all machines it can be improved by science.

Sometimes science can improve something old and familiar. Thus it can test traditional materials like bricks, set up standards for their manufacture, find out their most economical use. Or it may give us things which are wholly new. Steel frame construction, ferro-concrete, gas cooking and electric lighting all represented quite novel advances and were all due to science. As an example from to-day, take lighting. It will soon be possible to instal a new type of daylight lamp as part of ordinary household equipment—it's in industrial use here already. This is a vacuum tube in which the discharge causes fluorescence in a specially prepared material. In this kind of lamp, much less of the energy required is wasted as heat and so there is much lower current consumption, though it's rather expensive to instal. Whether it will pay to instal it depends on further scientific improvements.

Then there is the quite recent invention of plastic adhesive or glue which is also waterproof. This is already employed in the construction of our Mosquito bombers. In building, its most important use will be to waterproof plywood. Plywood is itself a modern invention and if we could have it waterproof and damp-resistant, it would enormously increase its usefulness.

Plywood provides a specially good example of the use of scientific *method*. In the old days, any sheet of plywood which had a defect such as a knot, had to be rejected. But a knot won't matter unless it overlaps another knot in the next sheet. So the statisticians were then called in and asked to work out, on the theory of probability, how often this was likely to happen for different sized defects. On the basis of their work the percentage of rejection has decreased

from around three-quarters to below half, and the actual output of certain plywoods has about doubled.

Let me go back to the waterproof plastic adhesive. Careful tests in Government Research Institutions, have shown that in an average house the outer wall of brick is somewhere about twice as thick as it need be for the support it has to give. So we could replace the inner half of the wall by something else which would give better heat insulation and so cut down fuel costs. One of the best materials is a synthetic boarding made from odd pieces of wood cut up fine.

Our new plastic could be made of any colour, applied to paper with a polished surface and then stuck on to the boarding. This gives a really lovely finish to a room, quite as attractive as the best distemper or wall paper; and it is cheap, washable and damp-resistant.

Other technical applications of science for housing have already been developed on a large scale in some other countries, such as the method of District Heating, by which heat is piped to all the buildings within an area, just as light or gas is now. Another is the Garchey system of refuse disposal for blocks of flats; all house refuse is tipped down a hole in your sink and then used, after treatment, as fuel to provide heat. We want such methods to be given a full and fair trial here.

Then science helps in another way by providing a firm basis for building standards. At the present moment various professional institutions concerned with building and architecture have set up a series of committees under the fatherly care of the Ministry of Works, and they're engaged in drafting Codes of Practice. These codes will incorporate all the best that the latest scientific knowledge can give, both as regards economy and efficiency of construction in all the different aspects of building. After they have been published—probably in a year or so—there will be no excuse for bad building, even though the codes

are not likely to be made compulsory. So after the war, if you're thinking of moving into a new house, ask if it has been built in accordance with the new building codes.

In some cases, by the way, public authorities will have to change their regulations if we're to get the best results. Good sound insulation is essential as everyone knows who has lived in a block of flats where all sorts of harmless and even desirable activities are forbidden to tenants because of the noise they make. The cheapest and simplest method of sound insulation between two rooms is to build the party wall double with an empty space in the centre: but this is now prohibited under the by-laws covering building.

In general, these by-laws have been perfectly satisfactory and indeed essential safeguards for traditional methods of building, but sometimes they haven't provided adequately for new methods and materials, or have even hindered them. Such as the possibilities of reinforced concrete construction—as I found out over some buildings we wanted to put up at the Zoo.

But new materials and methods often also run up against popular prejudice. Thus, steel frame construction makes it possible to free the outer walls from the business of supporting a building, so that one can turn them into a mere curtain; even corners could be wholly made of glass. Now when the first building of this sort was put up in Paris, great difficulty was found in insuring it, as all the Insurance Companies were certain it was bound to fall down!

A similar example is provided by the beautiful bridges of that remarkable Swiss architect, Maillart, who pushed the principles of ferro-concrete construction in bridge-building to their logical conclusion. The resultant thin slabs and delicate arches looked so unsubstantial—though really just as strong as the most old-fashioned stone or steel bridge—that many local authorities in Switzerland refused to have anything to do with them.

New methods like steel-frame and ferro-concrete construction—so-called pre-fabrication, the manufacture of parts of houses away from the site for assembly on the building site—new materials like glass bricks and plastics—all these are opening up quite new possibilities for architecture and building. We can, if we want to, indulge in all sorts of new possibilities—new shapes, great expanses of glass, movable partitions instead of party walls, new furnishings and many other things impossible to the traditional methods of construction. But in order to enjoy these new advantages, the public has got to get over their irrational or purely traditional prejudices. They must accustom themselves to the new possibilities of lightness and spaciousness, and of bringing the landscape to interpenetrate with the interior of the house. It is a curious fact that though the average man likes to have the latest possibilities devised by science incorporated in his car, and would never think of asking for one that looked like a 1900 model, in housing he tends to be shy of novelty and will try to go back to styles which were developed centuries ago, to meet the needs of those past periods, rather than going forward to the new style that is waiting to be born.

In any case, don't let's forget that beauty as well as comfort is something which our houses can give us. It is no more expensive to have good architecture and good design in fittings and furnishings than it is to have bad architecture—or no architecture at all—and shoddy, vulgar design.

One field where public prejudice certainly helps to retard advance is that of smoke abatement. Just think of it. About two-thirds of our population lives perhaps two-thirds of their lives under an artificial cloud, gloomy, dirty and unhealthy. Though a great deal could be done about this by regulations for industry, the bulk of this smoke-pall comes from domestic fires. The open fire is an attractive thing in the family living room, but if only the public would

accustom itself to use other forms of heating where possible, and at any rate insist upon smokeless fuel for the open grate, then we could go a long way towards healthier cities and more beautiful housing.

To come back to research, the Government Department of Scientific and Industrial Research founded in 1916 and its various branches, especially the Building Research Station and the National Physical Laboratory, have carried out an immense amount of research and testing on building problems and building materials.

Research—combined with new industrial techniques—has now given us the possibility of quite new standards of comfort, efficiency and beauty in our homes. But possibilities aren't actualities; and too often in the past, the knowledge provided by science has not been applied in practice. The most glaring example, I suppose, is the fact that long after we knew just what amount of different foodstuffs were needed for full health, something like a quarter of our population was still not properly fed.

To get these new possibilities realized in our houses, co-operation is needed from three different quarters—the builders and architects, the Government, and the public. The builders and architects are actively co-operating in all the Government schemes; and the public can always help in keeping them up to the mark. Further, the public—and that is all of us—must not let the immense need for quantity of housing which will face us after the war make us forget the equally great need for high quality in our houses. Otherwise, what will probably be the biggest housing programme in history will be unworthy of our country and its greatness.

But more demand won't give us what we want without the most careful planning and organization to carry it out. In particular, we need far-reaching Government decisions on various matters of principle. First on planning—the location of industry; the basis for compensation when land

or development rights are bought for planning purposes; the grant of compulsory powers of acquiring land; and so on. Secondly, as regards financial assistance for good housing. During the war we have, in one important sphere of life, that of food, adopted the principle that what counts is not the ability to pay, but human needs. It is the babies and the mothers that get the oranges and the extra milk —not the rich. In general, rationing is based on the idea that there is a minimum standard of diet, both in amount and quantity, below which we cannot afford to allow anyone to fall. Are we, or are we not, going to apply the same principle to housing? Are we going to say that there is a certain minimum standard of accommodation, comfort and beauty below which we as a nation cannot afford to allow anyone to fall?

I personally hope so. This should be a part of the basic platform of security which every citizen is guaranteed by his country. Not only that, but without such provision we shall never get the increase in the birth-rate that we need. At the moment our population is not replacing itself and will shortly begin to decline. If we don't provide sufficient houses where parents can bring up a reasonable-sized family in comfort and without constant financial sacrifice, the decline is likely to be rapid and perhaps catastrophic.

To sum up one may say that in regard to housing, scientific research has opened the door to new possibilities. It is indeed essential; but by itself it is not enough. All it can do is to tell us how to get what we want. We must find out what we really want; and we must finally have the will to get it.

THE SCIENCE OF BUILDING

By Sir Edward Appleton, K.C.B., F.R.S., Secretary of the Department of Scientific and Industrial Research,
and
Sir George Burt

I'm not a practical builder, and you may therefore wonder why I should presume to talk to you about building houses. But I am a scientist, and it's what science can do in the building of homes that I'm going to talk about. I would, however, like to make it clear at the start that I believe that building is both a science and an art. We scientists can only formulate the scientific principles which must be observed in the building of a house so as to give its occupier shelter and comfort. But we leave plenty of latitude for the architect, while still obeying those principles, to express himself in its design and lay-out. So please don't think of the scientist as a man whose chief aim is to condemn you to houses which may be efficient, but which are all alike and simply dreadful to look at. That's not his object at all.

But there's really a third party interested in this question of houses besides the scientist and architect, and that is you, yourself. In a recent broadcast a number of people said what they wanted after the war. They wanted first, a job, and second, a decent home. I'm glad therefore to be able to tell you that the staff of the Building Research Station of the Department of Scientific and Industrial Research are working on many problems intimately connected with the building of houses for after the war.

They're dealing, for example, with such matters as heating, ventilation, plumbing, artificial lighting, day-lighting, noise reduction, and so on. In their work they are carrying out accurate experiments on bricks, on walls and rooms, and

even on specially built houses. In this way they're gaining knowledge and finding ways of improving the quality and comfort of houses, without having to rely on guesswork.

Let me take an example to show you how a scientist tackles one of these problems. We've all suffered from the sort of house in which it's quite impossible to settle down to read in peace and quietness when there's a wireless on in the next room—or in which anyone having a bath late at night wakens up all the rest of the family. The problem is, of course, that of the transmission of sound and the scientist had to turn detective in tracking the various ways in which the sound vibrations travelled from one room to the next. Careful experiments showed that the sound does not all come straight through the dividing wall. It also travels along the floor and along the side walls. So if we want to stop this passage of sound we must go as far as we can to separate one room from the next. We must aim at designing our house so that it's not a box divided into rooms by partitions, but really a collection of separate boxes held together by a strong framework. There's no reason why the same principles shouldn't be applied to a lesser extent in any house or block of flats. That's the sort of way in which the discoveries of the scientist can help the architect.

Another problem that's received careful examination is that of artificial lighting. Science has been very busy in this field in close partnership with industry, and has now placed at your disposal a really remarkable series of improvements in lamps and fittings. But to take advantage of these, you've got to be a discriminating purchaser and resist the temptation to buy some other elaborate or ornate fitting which may catch your eye in the shop, but which is only half as efficient in lighting your room when you get it home.

Then, also, a great deal of scientific work has been done on ordinary domestic fires. The low efficiency of some of them is really disgraceful. This should be regarded not only as a drain on the owner's pocket but also as an unjustifiable

waste of precious fuel. There's simply no need for us to have in our new homes fires that send most of their heat wastefully up the chimney or through the fire back to an outside wall. It may surprise you to learn that the room heating efficiency of many fires could, by scientific design, easily be doubled or even trebled.

I've only time to give you one more example of the work of our scientists and this time its a case of depressing, rather than raising, expectations. You've no doubt heard people saying that after the war we shall see houses built entirely of "plastics"—those new materials which are so light and so easily moulded—and which Sir Lawrence Bragg discusses in the next article in this book. But by making mechanical tests it has been possible to say whether such materials can be used to replace say steel girders or wooden joists in buildings. Unfortunately, the plastics have not got very high marks in this test. I cannot go into details, but I think it's safe to say that although plastics will, of course, find many uses inside the modern house it's fairly clear that it's unlikely that our houses will be built entirely of such materials.

Now let me hand you over to Sir George Burt, who is not only a practical builder, but also one with a real appreciation of what scientific research has done and can do to help him.

SIR GEORGE BURT, Director of a firm of Building Contractors

Since the days when our forefathers were content to live in a cave there is no doubt that we've advanced, but it is also true to say that up to comparatively few years ago the advance was made by rule of thumb methods. As general education and standards advanced, so, too, our requirements have risen. It is not very many years since the standard of one bathroom in the larger-sized houses, and certainly no bathroom at all in the smaller ones, was

accepted as all that was necessary. It is perhaps twenty years since it began to be accepted that it might be desirable to have baths in every house; but now it must be very unusual for any house to be built without one. They have not yet all got running hot water, but we live in hopes.

The amenities that perhaps a few people hoped for in the old days—the luxuries of days gone by—are now looked upon by everyone as necessities—light, drainage, power, water, sewerage; but even so, there are still areas in the country where many thousands of people live in houses without piped water, and many more without main drainage, light or power supplies.

I think, perhaps, that you don't realise the extent to which Science can help in seeing that these things which might even now be called, and certainly up to a very few years ago were called, "refinements," can be given easily and without necessarily any appreciable expense. I suppose the most common source of annoyance to you is the noise of your neighbour's wireless, either in the flat above or in the next-door house. There is no reason for this; science to-day has information which can prevent it. It may be true to-day that this noise abatement might cost money, but there is no reason why it should always do so, and this is true of other sources of annoyance. Why do your walls run damp after a frost? Why, when there is even only a few degrees of frost, do your pipes freeze? All these annoyances can be easily avoided—and, if science is made to play its part properly, it needn't cost you any more money. What is really wanted is a better understanding between the authorities responsible for building houses and the architects and the builders; and, what I think is perhaps the most important of the lot, a firm insistence by you that you are going to have these things put right, and that you don't expect to pay more money for them. You must get the building industry in its very widest sense to realize that, and make them understand that you will see that you do get those things done as you want them.

It's up to you. Science is there waiting for you to insist on it being used.

Advances like this cannot be restricted to the building industry. Industries which have grown up since the war have got to come into it. You have got to use the knowledge acquired in aeroplane building and small ship construction and the hundred-and-one things—new things—which the war has shown us and taught us. So many of them can be adapted to help give you that better house which you want. Who would have thought that the fastest bombing aeroplane in the world—the Mosquito—would be made of plywood and balsa and glue, with nothing but its ailerons made of metal: Many of these materials which the war has developed can be brought to peacetime uses.

In house building we are inclined to be one-track minded; tradition is good but it can be overdone. Your brick-built house of to-day is stronger than it really need be for mere stability—it will certainly long outlast its usefulness as a habitation. Long before it is worn out it's likely to be completely out of date. While it may continue to give you shelter it won't give you those amenities that you will increasingly come to expect. There must be tens of thousands of houses in the country to-day which although they may not come within the Slum Clearance Order are quite definitely hopelessly out of date.

At the same time in striving after new things we are inclined to forget the virtues of the old. In the old days if you built a house more than one storey high you had to use mass—thick walls—to give it stability. With the improvement in materials and the craze for cheapness that mass was cut down; but in cutting that mass down you lost qualities which have never been put back in any other way—qualities of insulation from sound, insulation from cold and moisture. In the old-fashioned house you remember walking in from the outside on a bitterly cold day or a sweltering hot one and feeling a sense of relief that you have

got into a more comfortable temperature; but the modern house doesn't give you that to-day. It can roast you in summer and freeze you in winter. Science will show you how this can be avoided, and how you can work to the old standards if science is allowed to play its part and proper use is made of new materials and new ideas.

To take another example—this time rather different. One can hardly fail to doubt that the war will enormously increase motor transport—more roads and better roads will be wanted. It seems to me that road building has progressed very slowly. We have certainly been spending more and more money on road-building in recent years but it's been spent on the surface. Your road specification normally lays down certain stipulations, but actually the only precaution taken in putting a road on a soil of doubtful or unknown strength at present takes the form of a thicker, heavier and, therefore, more expensive top, instead of really taking the trouble to find out what your soil will actually carry, and then building a road to suit it. The knowledge of science has not yet been properly applied. No architect or engineer would put a structure on a doubtful foundation, but there doesn't seem the slightest hesitation in doing so with a road, and spending more and more money in putting on a heavier and stronger top in a blind hope that it will last. This is certainly one branch where science has not yet been given a chance to prove its usefulness, and in road building there are many more.

We must hope that everyone concerned will come to realize the importance of what is known as the science of soil mechanics, and see that the money is spent where it ought to be spent—on the foundations—and not wasted by putting heavy, expensive tops on bad and unsound bottoms.

At the end of the war—immediately after the war—housing demands are going to be far greater than the industry as at present constituted can hope to cope with;

and it seems to me that there may be a serious danger of a lowering of standards rather than the raising of them. In my view there's no necessity for this. Let those responsible use the scientific knowledge which is at present available and you can have better houses than you had before the war—if not more quickly built, at least more quickly fit to live in; by which I mean they will take a shorter time to dry out and they won't necessarily be more expensive—and when I say "necessarily" I mean in relation to every other standard.

We've learned from the mistakes made after the last war, and there's no reason why these mistakes should be repeated. One bar to progress has been, perhaps, that you are too conservative in your requirements, and in most of your habits, Most of you are very wedded to open coal fires, but you forget, or perhaps don't know, that most of your heat is going up the chimney. With a little more flexibility in your requirements, and a few simple structural alterations in your house, this waste heat might be made to warm the whole house more thoroughly. If your children come home from school with homework to do, they want somewhere to do it quietly. In the winter to-day it would probably be too cold for them to use their bedrooms—but why should it be? We ought to encourage appliances that can help you not to let so much waste heat go up the chimney, and at the same time utilize that heat to better advantage where t is wanted. But to achieve this you'll have to be rather less et in your ways. Science can help in solving these problems, ›ut your co-operation will be needed in getting the results ısed; and your interest in what is being done will ensure hat proper use is being made of this knowledge, and that ‚ou are not being fobbed off with something which because t was good twenty years ago is good enough to-day. It's up o you to see that you get all the advantages which present-lay science is able to give you.

In a broadcast such as this, I should be foolish if I entered

into the realms of cost and finance. I'll only express the hope that we shall not endeavour to squeeze down costs to the pre-war slump level, extracted out of an industry by exploiting the position of its 20 per cent record of unemployment; it will indeed be a tragedy if we allow our standards to fall and let the fruits of scientific investigation over years rot on the ground. Let us set our standards high, let us realize that we must achieve these standards quickly and at a reasonable cost. I for one am convinced it can be done if we go the right way about it.

PLASTICS

By Sir Lawrence Bragg, F.R.S., Cavendish Professor of Physics in the University of Cambridge

What are plastics? We hear the word "plastic" very often nowadays. You will have noticed that many objects of daily use which were formerly made of natural substances are now being made of some kind of artificial preparation. Buttons are a good instance. When they were not made of metal they were generally made of bone, or of shell like the mother-of-pearl buttons affected by the Coster Pearly King. They are now made of an artificial bone-like substance, a plastic in fact, and in addition to the humble button of the trousers variety, one can get them in all sorts of shapes and sizes and brilliant colours. Toothbrush handles are of a tough transparent plastic instead of bone. Their bristles are of nylon—another plastic—instead of pigs' bristles, and they last much longer. Knife handles, mugs, the handles of umbrellas and the clasps of handbags, electrical fittings like plugs and switches, the case of your radio set, are made of plastics. The stiffeners in ladies' stays used to be made of whalebone. If there still are such things as stays, of which I am not sure, one would not now have to rifle the mouths of whales to get their vital parts. I remember my surprise when I first heard of a chemist friend with whom I was playing golf that the tees I was using were made from milk. By some sort of chemical juggling the plastic expert starts with such ordinary things as coal, limestone, salt, water and air and produces strong, light durable materials which can be used for a host of purposes.

The very fact that plastics are made of such ordinary materials, so unlike the final product, shows perhaps best of

all what has been achieved. The chemist is copying nature. Grass feeds on water and air, and with the help of sunlight and a speck of mineral salts it grows its blades. The sheep eat the grass and turn it into wool. We have learnt how to carry out in the laboratory and factory what is done by living matter. Plastics fill a gap in the list of materials we need which used to be filled by such things as bone and horn and even wood.

To explain the main feature which is the basis of all these plastic materials, I must ask you to bear with a few words on the way in which chemical compounds are built up, particularly those compounds which are called organic because they play so large a part in living matter.

Here is an analogy to help us to see how chemical molecules are built by atoms. Most people are familiar with Meccano sets—it is rare nowadays to find a boy who has not built things with this delightful invention. There is a set of standard parts, such as different lengths of metal strip, angle pieces, plates with holes in them, and they are fastened together with nuts and bolts. With just a few standard parts one can build up many complicated structures such as bridges and cranes. Now atoms are like the standard parts in Meccano, while molecules are the structures built from them. The nuts and bolts which fasten the Meccano pieces together are the chemical bonds which fasten atom to atom in the molecule. The number of different kinds of atoms is not very large, some ninety or so in all, but, of course, by combining them in various ways an infinite range of chemical compounds can be formed. Now in organic compounds in particular, practically the whole structure is built of atoms of four kinds, carbon, oxygen, hydrogen and nitrogen. These are common atoms—coal is mostly carbon, water is hydrogen and oxygen, air contains oxygen and nitrogen. In some organic compounds other atoms play an essential part, just as in Meccano most of the structures can be built up of the ordinary pieces but we need certain special bits

such as gear wheels to finish off our crane. Sulphur, phosphorus and chlorine are examples. The complex molecule called haemoglobin which takes the oxygen from the air and conveys it in the blood to all parts of our bodies, is a big structure of about ten thousand atoms. In this vast array, there are four atoms of iron which have an essential part in doing this work. Such special atoms, however, are very few. The main structure is always built up of carbon, oxygen, nitrogen and hydrogen. They are so useful because they have got convenient links, like the Meccano nuts and bolts. Carbon in particular has four available strong links for atom-connection, it is what we might call the fundamental standard bit of Meccano in all organic compounds.

Now the chemical molecule is a definite structure containing a certain number of atoms linked in a certain way. Water, for instance, is a collection of molecules each of which is two atoms of hydrogen linked to one of oxygen. A benzene molecule is six carbon atoms in a ring, each with an atom of hydrogen tacked on to it. Each kind of molecule is like one of the pictures in the Meccano book of instruction, some definite bit of structure which can be made from the parts. But now imagine a boy let loose with a whole set of identical units with their bolts, who idly set about joining bits all over the place, going on and on till he had a tangled mass on the floor, all of which was tied together in a random way. There is no end to the process, he could go on as long as he had spare parts. He would have done exactly what the chemist does when he makes a plastic.

✓How is a plastic made? In many cases the chemist starts with quite small molecules, so small that they slither easily over each other and make up a liquid. By some means these molecules are then made to link up with each other in all directions, so that they become a kind of tangle which is stiff and solid. Heat alone is often sufficient to do this. In making table knives, for instance, the steel blades are stuck into slits at the bottom of a nest of little boxes, which are

moulds for the handles. These are filled with liquid and the whole is heated, when the liquid solidifies into an ivory-like solid gripping the spike on each blade. This sounds very simple, but of course, the secret lies in finding liquids whose molecules behave in this way. Perhaps I can best explain the kind of molecule which does the trick by my Meccano analogy. It must be a molecule which has connecting links to spare, but these connecting links must be, so to speak, hidden away inside it and not active till we are ready to use them. If this were not so, the molecules would be all sticking together at the start, whereas the whole object in plastic making is to start with something liquid or soft which can be poured or moulded, and then turn it into a hard solid. Suppose in Meccano we had a host of paired parts, each pair being fastened together by two bolts. They would all be separate and slide over each other quite easily (like a liquid). But by undoing one bolt per pair, we could use the spare bolt on pair A to fasten it to B, and then take the spare bolt on B to fasten it to C, and so on indefinitely, getting long strings. If this is done in a random way, the result would be a tangle of such strings so interwoven that it would be a solid mass. I will use another analogy because it is so important to get this main idea clear, which is at the bottom of all plastic-making. Imagine a number of couples dancing in a hall. Each couple is a molecule, joined together by a double bond, their arms. Since there are no links between one couple and another, the whole mass of dancers is fluid, and movement is possible. But now suppose one link in each couple be broken. Each lady and gentleman has one hand occupied with holding on to her or his partner, but the other is free and can clasp a similar free hand of a neighbouring couple. There will be such an intertwining of clasped hands that movement would become impossible. The fluid dance turns into a solid mass, composed of criss-crossing chains of people holding hands.

This is just what happens in one whole class of plastics.

Carbon atoms can be linked together in pairs by double bonds. By heating such molecules, and so knocking them about violently, one of these bonds can be opened, providing a spare link to which the molecule can be attached to a neighbour, and then to another and so on. Another trick to unite the molecules is this. A small bit is knocked off each of two molecules, leaving a link to spare, and this is used to bind them together. For instance, a hydrogen atom can be knocked off one, and an oxygen atom together with a hydrogen atom off another. The discarded atoms unite happily to form a molecule of water which goes off on its own, and the links so set free tie the two molecules together. If each molecule then has a hydrogen which can be knocked off at one end, and a hydroxyl (that's the name for oxygen and hydrogen) at the other; they are like the male and female screws at each end of a set of drain rods, and the process of uniting them into long strings can go on indefinitely.

This endless linking up of simple molecules is no new discovery. Nature invented it long ago. In plants, for instance, the chemical processes somehow produce a simple kind of sugar unit. These tack together by shedding off water in the way I have just described, and built up the long strings of cellulose. Some plastics make use of these long cellulose strings provided by nature. A chemical agent is used to loosen the strings from each other, when the cellulose mass becomes soft so that it can be moulded or squirted into threads through a die. The loosening chemical is then removed and the mass hardens in its new shape. A very old friend of this kind is celluloid; made of nitrated cellulose with the help of camphor. It was discovered in 1869. More recent ways of doing the loosening by chemical means have resulted in one class of artificial silks, and also in the cellophane which is so widely used nowadays.

The living matter in animals and plants is called protein. Protein molecules are exceedingly complex and their structure is still largely unknown, but we do know that they have

a kind of backbone consisting of a long chain in which two carbon atoms alternate with a nitrogen atom. In living matter these chains are built regularly into the huge protein molecule, but a random tangle of them, no longer alive, is used by nature to build hair, silk, wool, and horn, nails and hoofs, all of which might be called natural plastics. The casein from milk is a protein, and can be used in the same way to make artificial plastic.

Most of my listeners must have made a plastic at some time themselves. You do it in fact every time you use an oil paint. Oils are composed of rather short chains of carbon atoms. When the oxygen of the air gets at certain kinds of oil like linseed oil, it builds cross links between these chains and turns the whole into a solid. We say "The paint is drying," but actually it is setting as a plastic.

Before I leave this question of structure I should say something about the difference between two main kinds of plastic. One kind of plastic becomes soft if it is warmed up, and hardens again on cooling. It can be dissolved by suitable chemicals and thrown out of solution again. The other kind, once it has set, has set for ever. It cannot be softened or dissolved. What causes the difference? It is a simple matter of the number of links. The first kind, the thermoplastics, have two links per molecule. With two links, all one can do is to build up long chains. They may be so tangled up as to make the plastic hard, but they can still be separated or slide over each other when the whole is warmed up. The second kind, the thermo-setting plastics, have more than two links, say three or four. Probably you will see at once that not only can they join in strings, but also these strings can be linked sideways to each other in all sorts of ways. Such a mass cannot be softened or dissolved unless it is completely broken down. The cabinet of your wireless set is probably a plastic made from phenol with three links and formaldehyde as a cross-link; it is an example of a thermo-setting plastic.

Of what service are these plastics in everyday life? Think first of the properties of a plastic, its cleanliness, permanence, lightness and unbreakability. Then there is the ease with which many of them can be given a colour which is not on the surface but part of the material. Finally, since they start as liquids or powders and then harden, they can be made into any shape. It is a wonderful combination of properties. Instead of natural textiles like silk we can use artificial silk and rayon and nylon, which are cheaper and stronger. Natural textiles can be improved—for instance, crease-resisting cotton is made so by soaking with liquid materials which are then hardened into a plastic inside its fibres, making it springy. Transparent plastics are used for wind-screens and turrets of aeroplanes—lenses for cameras and spectacles are being made of plastic. One of the most interesting developments is that of using plywood with plastic glues. The wood is used as very thin sheets gummed together with special plastic cement. In this way one can build sheets of any rounded shape with no joints, as in the plastic aeroplane. Not only are the sheets very strong, but they are also very lasting and resistant to weather. This opens up all sorts of possibilities in the decorative side of housing and furniture. Artificial rubber is a plastic. Nearly every natural product—rubber, silk, guttapercha, bone, horn, can be replaced by a synthetic plastic. Are we emerging into a plastic age? We must be careful to keep a sense of proportion. Although plastics are made of cheap and plentiful raw materials, they require new and complicated machinery to handle them. Ordinary materials of construction, like the brick, are still very cheap and plentiful—we are not likely to go all plastic. Our architects and designers must be won over to apply their art—the exciting possibilities of a new material generally lead to atrocious bad taste in its employment at first. We may therefore expect to see plastics not so much displacing existing materials, but adding to them to an increasing extent in articles we use in everyday life.

4

CLOTHING AND FABRICS

By Professor J. B. Speakman, D.Sc., Professor of Textile Industries in the University of Leeds

The fibres used in making clothing may be animal, vegetable or mineral in origin. Silk and wool are animal fibres; cotton and flax are vegetable fibres; and asbestos, which is used in making fireproof clothing, is a mineral fibre. Every one of these fibres has a complicated structure, but the scientist wasn't encouraged to take an interest in textiles until after the end of the first world war. It's an ill wind that blows nobody any good, and it was because the country couldn't wage a successful war without help from the scientist that our industrialists were led to believe that science might be able to solve some of their peace-time problems as well. Since 1918, scientists have been at work on each of the main textile fibres and it is now fair to say that textile technology is no longer a craft but an exact science. Apart from textile *designers*, the training of those who will occupy responsible posts in the industry must be essentially scientific in character. The well-being of the whole industry depends on the recognition of this truth.

Faced with the problems of the industry, the scientist began to build up an exact knowledge of the composition, structure and properties of the fibres concerned. At first, progress was slow, because Nature is the greatest of chemists and fibres are among the most complex of her products. So the attack had to be a combined operation by the physicist and the chemist, and their joint work has given us a very clear picture of the structure of most textile fibres, even wool. Why even wool? Well, because it is only 20 years since a distinguished scientist used to tell his students that the

structure of wool is so complex that it would never be discovered.

We now know that all fibres are made up of very long molecules, which are arranged more or less parallel to the length of the fibres, and are held together sideways with varying degrees of firmness. Where the sideways cohesion is small, as in the case of cotton, the fibres are easily dissolved and the solutions are used to make rayon. For a long time the chemist has been anxious to dissolve wool, too, because then he could make rayon from waste wool and the rags of the rag-and-bone merchant. If this could be done, it would revolutionize the shoddy trade, or, to give it its proper name, the Low Woollen industry.

Actually, the chemist has discovered two good ways of dissolving wool, but only after long and difficult work. Wool is extremely difficult to dissolve because in this case the long molecules are linked together by strong chemical bridges; the structure is something like a ladder, where the sides of the ladder are the long molecules and the rungs are the chemical bridges between them. But the structure is not rigid like that of a ladder, because the long molecules are folded down in concertina fashion. The consequences of this concertina ladder arrangement are very important.

When wool fibres are pulled, they stretch very easily because the coiled molecules unfold, or, if you like, because the concertina opens out. When the stretched fibres are released, they contract, because the molecules fold up again. If the fibres are damp, they return exactly to their original length, even after they've been pulled out to nearly twice their length. The damp wool is just like a piece of elastic, and this is the reason why fabrics made of wool do not crease easily during wear. If they do crease, the creases disappear when the garments are hung up for a short time in a wardrobe.

The crease-resistance of wool made chemists wonder whether other fibres, like cotton, which creases very easily, could be

given the same property. The long molecules of cotton are not folded and when the fibres are stretched, or bent, or folded, the molecules slip over one another and the stretch, or bend, or fold, becomes more or less permanent. It was difficult for the chemist to make the cotton molecules fold up like those of wool, but he could bind them together so that they didn't slip over one another. He made simple chemicals react together inside the fibres to form a plastic —a plastic which you can look on as a kind of reinforcement of the weak cotton fibres. When the fibres of cotton fabric are permeated with plastics in this way, they show a crease-resistance similar to that of wool, and the discovery—it was made by Manchester chemists about sixteen years ago—has made cotton fabrics far more serviceable than ever before; and the process is even more effective with some of the rayons.

Unfortunately, the perfect elasticity of wool, which is so valuable in preventing creasing, is by no means an unmixed blessing. It causes one of the two kinds of shrinkage to which wool fabrics are liable. After newly-woven fabrics have been washed, they are stretched to standard width and dried in this state. If the fabrics were sold in this condition, they would naturally shrink as soon as they were laundered, or even on becoming damp in the rain, because the stretched fibres would contract. So before the fabric is sold, it is wound on to a perforated roller through which steam is blown. The steam escapes through the fabric and has the effect of annealing the fibres in their stretched state, so that they are afterwards unable to contract, even in water. The process is a very old one, but the exact reason why the fibres can be annealed in this way was discovered only a few years ago. I must give an outline of what happens in order to explain how the chemist was led to develop a number of improved types of wool.

When the wet fabric is stretched to standard width the folded molecules uncoil and the concertina opens out.

Steaming breaks down some of the rungs between the long molecules of the ladder-like arrangement and lets the fibres relax. When the rungs are broken, the fibre is seriously weakened, but fortunately for the user of wool textiles, further steaming causes new rungs to be built up again in new places while the fabric is in its stretched state. These new rungs prevent the fibres—and the fabric—contracting in water. As soon as the chemist had found out how the old rungs are broken, and how the new ones are built up again, he at once saw that both processes could be helped by means of simple chemicals, and more effective methods of preventing one kind of shrinkage were the result. Not only so, but he devised simple methods for breaking down the rungs and rebuilding new ones at ordinary temperatures, instead of in steam.

Research is full of surprises, and these new methods of fixing the size and shape of fabrics at low temperatures seem likely to simplify the permanent waving methods of the hairdressing trade. Chemically, wool and hair are very similar, and present-day permanent waving methods are very similar to the setting processes of the wool textile industry. The hair is wound on a curler, just as the fabric is wound on a perforated roller, and it is steamed in the curled condition. When the rungs between the long molecules of curled hairs are broken, the fibres relax and the curled state is afterwards made permanent by the formation of new rungs, just as in the case of the stretched fabric. Since the breakdown and rung-building processes can now be carried out at ordinary temperatures, who can doubt that it will soon be possible to give hair a permanent wave at ordinary temperatures, without the discomfort of present-day heat treatments?

In ways like these, the chemist was led to investigate the possibility of replacing the rungs in ordinary wool by others which would remove some of the weaknesses in wool which offend the user. Ordinary wool is very easily damaged by

alkalis, and no one would dream of boiling wool materials in a solution of washing soda, say. In fact, no one but a member of a decontamination squad would dream of boiling wool garments in water. This is because one of the rungs in wool is very easily broken by alkalis and hot water. To overcome this weakness and make wool useful for many new purposes, the chemist has altered the rung and made it highly resistant to alkalis. So the chemist is making wool, as well as cotton, much more serviceable.

But this isn't the only importance of the work. These rungs in ordinary wool which are so easily broken by alkalis and hot water are very easily broken by the digestive juices of the moth grub. This allows the grub to use wool as food, and even if I can't eat my hat, the moth grub can. The new rungs which the chemist has been able to make in wool cause the grub to suffer from chronic indigestion, and some of the chemically modified wools are completely immune to attack by moths, besides being resistant to the alkalis they may meet with in laundering. So greatly improved wool will be available for general use after the war, and it is good to know that the methods for achieving these very desirable results were first evolved in this country, though they have since received a lot of attention in the United States of America.

Before leaving the subject of moth attack, I must mention that other methods of giving complete protection against moths had been developed by chemists in most countries of the world some years before the war. One such method was to dye wool with a colourless dye which is poisonous to the moth grub but not to human beings. In contact with such wool the grub must die either of starvation or of poisoning from the first bite taken. The treated wool has no smell and, in the words of a well-known advertisement, "only the moth can tell" that it is indigestible, and the reward of his discovery is death.

Wool has another peculiarity, which is sometimes useful

and sometimes a plain nuisance. Wool and hair are very similar, and if you have any hair left after five years of war you can see the effect I want to talk about by taking a hair from the head and rubbing it lengthways between finger and thumb. The hair travels out of the fingers because its surface is made up of flat cells which overlap one another like the slates on the roof of a house. Under a rubbing action, the surface acts like a ratchet and causes the fibre to move towards its root end, away from the tips of the protecting cells. When a wool fabric is rubbed in soap solution every fibre begins to creep in this way and the cloth shrinks until in the end it is a felt. In making fabrics like blankets, this property is extremely valuable because it allows the fabric to be consolidated in readiness for the next process, where the surface is raised with teazles to give a covering of loose fibre for warmth. But with socks and underwear the shrinkage is nothing but a nuisance. It can be prevented by treating the fabrics with a solution of chlorine in water. What happens is that the chlorine breaks down the very same rungs between the long molecules of wool as are attacked by alkalis and moths. When these rungs are broken down in the surface of the fibre, its skin swells in soap solution, and the ratchet—which is waiting to cause fibre movement—is made so soft and pliable that movement and shrinkage are impossible. As soon as we knew exactly how chlorine prevents felting, other ways of bringing about the same result were more or less obvious. To cut a long story short, there are now at least ten new methods of making wool unshrinkable, and the fact that they are all British is, I like to think, because the molecular structure of wool was first worked out in this country.

Even more striking examples of the practical value of scientific work on textile fibres can be found in the rayon industry. At first, the chemist's aim here was simply to make a cheap imitation of real silk, which has such remarkable strength and lustre. As all fibres consist of long molecules,

the chemist chose as his raw material the long molecules provided by Nature in substances like cotton and wood pulp. The cotton is dissolved in various ways, one of the more important being discovered by Cross and Bevan many years ago, and the solution is squirted through tiny holes into a hardening medium. Here the long molecules are thrown out of solution as fine filaments, which are stretched to draw the molecules into line and to promote the rung formation which is needed for strength. The rayons produced in this and similar ways have found an established place in the textile industry, and the chemist is now busy trying to make fibres which resemble wool, at any rate in some of its properties. Wool is a protein; and the long molecules he uses in his efforts to find a substitute are obtained from milk, monkey nuts and soya beans. The fibres made from milk are now being used in the manufacture of felt hats because, curiously enough, mixtures of wool and milk-fibre felt much more quickly than wool alone, even though the milk fibre doesn't possess the ratchet-like surface structure of wool.

But the ambition of the chemist knows no bounds, and the latest types of synthetic fibre are made from long molecules which he himself makes from simple substances. You'll recognize an echo here of something Sir Lawrence Bragg has written in the previous chapter about Plastics. Some of the early products were very odd. I forget which bird it is that is supposed to fly backwards to see where it has been, but the chemist seems to have indulged in the same kind of aerobatics, because some of the first fibres just disappeared in soap solution, like some of the earlier rayons. A strongly developed sense of humour is needed to appreciate such materials, but they will at least be useful to the conjurer. All such difficulties have now been overcome and the American fibre nylon, which is made from benzene, is remarkable in being at least as strong as real silk. Its invention has spurred on the older rayon industries to further endeavour with the result that they, too, can now provide fibres which are

considerably stronger than silk. Such materials have found important war-time uses, and it is now obvious to everyone that synthetic fibres must no longer be regarded as inferior imitations of natural fibres.

So far the chemist has not been able to make a good imitation of wool, but his attempts have begun to worry the wool-growing countries. Sheep-breeding will always be an important industry in Australia, South Africa and New Zealand, because of the demand for mutton, but wool provides a large part of their revenue, and it is important to consider what steps such countries can take to meet the competition of synthetic fibres. One safeguard is the more intensive prosecution of research on wool, which, as I have tried to show, is capable of correcting the defects of the fibre and widening its field of utility. A second lies in research on the by-products of the greasy fleece, particularly wool fat, which represents about 10 to 20 per cent of its weight and is commonly met with as lanoline. The chemistry of compounds related to wool fat is now well advanced, and the time has surely come for the chemist to be given an opportunity of making wool fat as valuable a product as the wool with which it is associated.

5

EXPLOSIVES

By Professor John Read, F.R.S., Professor of Chemistry in the University of St. Andrews

Years ago, as a boy in a Somerset village, I sometimes amused myself and impressed my friends by filling a jam-jar with water, turning it upside down in the village horse-pond, and poking the mud beneath it with a stick. Bubbles of marsh-gas, released from the bed of the pond, rose through the water and soon filled the jar. When I held a lighted match near the mouth of the inverted jar, the gas took fire and burnt quietly with an almost invisible flame. Occasionally, however, when a good deal of air had got into the jar, the mixture exploded with a very pleasing pop.

It's a long way from my village horse-pond to Hamburg and Berlin, and still further, you may think, from marsh-gas to "block-busters"; but the links in the chain are clearly traceable, so why not let us see how they run?

Marsh-gas, which arises from sodden and decaying vegetation, is the simplest of hundreds of thousands of organic compounds. Organic compounds are substances containing carbon. Marsh-gas, also known as methane, is a hydrocarbon, or compound containing carbon and hydrogen only. It is the same as the fire-damp of coal mines. Its molecule, or ultimate chemical particle, is written CH_4, because it is formed by the combination of one carbon atom, C, with four hydrogen atoms, H_4. These molecules are excessively minute. A hollow pin's-head would hold enough of them to provide several million each for every man, woman and child in the world.

When marsh-gas burns, it undergoes a chemical change known as oxidation. Through reaction with oxygen, which

The many perils that environ
The man who meddles with a siren
Are naught beside the ones that he
Invites, who flirts with TNT.

An explosion is usually an exceedingly rapid oxidation, or burning. An explosive is a material capable of developing a sudden high pressure by the rapid formation of large volumes of gas. The explosive power of marsh-gas mixed with oxygen is relatively feeble, because the expansion is due entirely to the heat effect: except for the heat set free in the process, the volume of gas in this example would be the same before and after the burning. Enormously more powerful effects are produced in the explosion of suitable liquids or solids. A given space will accommodate a much greater weight of an explosive in the liquid or solid form than as a gas. This economy of packing in liquid and solid explosives is one of the leading factors in producing great pressure when the explosive suddenly gasifies. The second factor is the simultaneous liberation of vast stores of heat, leading to a further expansion.

When solid gunpowder explodes, it produces 500 times its own volume of gases, measured at the ordinary temperature; but the liberated heat causes a further eightfold expansion to 4,000 volumes. Nitro-glycerine is still more powerful: one volume of this oily liquid gives rise on exploding to 1,200 volumes of gas, expanding again about eightfold through the action of the generated heat to some 10,000 volumes. That is to say, a thimbleful of liquid nitro-glycerine is transformed in the twinkling of an eye into 60 pints of gas at a fierce heat exceeding 5,000 degrees Fahrenheit. On the same scale, a foot-rule would leap out to a length of two miles. Once started, nothing can stop or moderate this sudden burning and release of energy.

Why is nitro-glycerine so much more powerful than gunpowder? Briefly, because in gunpowder the fuel and the

oxygen are done up in separate packets, or molecules; whereas in nitro-glycerine both the fuel and the necessary oxygen are packed together in the same molecule. In gunpowder, the fuel specks of carbon and sulphur lie side by side with the oxygen supply, contained in separate specks of nitre. In nitro-glycerine, the fuel atoms of carbon and hydrogen are arranged in the same molecule with a sufficient number of oxygen atoms for their complete burning. The mixing here is done inside each infinitesimal molecule: it is of the most intimate nature we can imagine. Most modern explosives are of this kind: nitro-glycerine, guncotton, cordite, tri-nitro-toluene, all contain the fuel atoms and the oxygen atoms arranged within the same molecule.

The molecules of such explosives are very delicately poised. The fuel atoms are temporarily held apart from the oxygen atoms by molecular policemen, consisting of atoms of nitrogen. Their lot is not a happy one; for they must always be on duty. The moment these pillars of molecular law and order relax their vigilance, there's a molecular dog-fight, virulent and contagious, and the countless legions of molecules collapse, with spectacular unanimity.

There are several ways of distracting the attention of these molecular policemen, so that explosion may occur. Sometimes heat does it, sometimes friction, sometimes concussion. Explosives are very temperamental. For instance, both tri-nitro-toluene and cordite will suffer the impact of a bullet without exploding; but mercury fulminate explodes when struck by a hammer, and nitrogen iodide is so very touchy that one would hesitate to sneeze near it, and a fly using a crystal of it as a landing-ground might no longer interest a spider. Again, cordite and tri-nitro-toluene burn without exploding when ignited in the open air, but mercury fulminate and lead azide explode with great violence when ignited under any conditions.

Many of the powerful modern explosives can only be roused to full explosion by means of detonation. In this

process of detonation, discovered by Nobel in 1864, the explosion of a small charge of an initiatory explosive or detonant, such as mercury fulminate, sets off the main explosive lying near it. These detonants, which may be exploded by percussion or a spark, set up violent shock waves. So, when tri-nitro-toluene is fired by a suitable detonator, instead of burning quietly it undergoes an instantaneous collapse, caused by an explosive wave; this originates in the detonator, and moves through the TNT at a speed of more than four miles a second. This is what happens when a bomb or shell explodes.

Explosives such as gunpowder and cordite, which always burn comparatively slowly, without detonating, may be used as propellants. It's gunpowder that sends the shot after the rabbit and cordite that sends the bullet after the German. Other explosives, such as TNT, lyddite and guncotton, burn rapidly to detonation when confined. These are known as high explosives. They cannot be used as propellants, because they would detonate and shatter the weapon. High explosives are used for filling shells, bombs, torpedoes and mines, and also for demolition work.

A few miles from the fine horse-pond I mentioned just now, there is a grey old town called Ilchester. It stands at the junction of the Fosseway with the Roman road to Dorchester; but Ilchester is older even than the Roman roads. Here, in 1214, was born Roger Bacon, the earliest of the great scientists of England. It was in a Latin text, written in 1242, that Bacon first made known the composition of gunpowder, the oldest explosive. This Franciscan monk was perhaps the first to make gunpowder explode and to realize its power. According to a medieval legend, another monk, the mysterious Berthold Schwarz of the Black Forest in Germany, first used it as a propellant.

The introduction of modern explosives, beginning about 1850, was due largely to the Swedish chemical engineer, Nobel, who invented dynamite, blasting gelatine and

ballistite, and founded the Nobel Prizes—including the Peace Prize.

Modern explosives are made chiefly from fats, cotton and coal, all of which are natural sources of energy, containing the fuel atoms, carbon and hydrogen. In the manufacture of explosives, the glycerine from fats, the cellulose of cotton, and the benzene and toluene of coal-tar are treated with nitric acid, under special conditions, in order to introduce the necessary oxygen and nitrogen atoms into the molecules. The nitric acid, formerly obtained from Chili saltpetre, is now prepared chiefly from atmospheric nitrogen. Indeed, to the Germans—because of British sea-power blocking the importation of Chilean nitrate—the manufacture of nitric acid from the air was essential before the war of 1914–1918 could be undertaken. So they made sure of it before committing themselves.

Through the intervention of plant life, fats, cellulose and coal also originate from the air, this time from gaseous carbon dioxide and water vapour. Nitric acid, fats, cellulose and coal—they all come ultimately from the air. Explosives are thus slowly woven from atmospheric gases, unto which, in the moment of explosion, they return—shedding suddenly their fabulous stores of strangely acquired energy, caught up mainly from solar radiation by the living plant.

How does all this that I've been talking about affect you? Economically and industrially, the manufacture of explosives is closely linked with the production of such familiar commodities as fats, glycerine, soap, cotton, coal, dyes, drugs, petroleum, and fertilizers. In the great chemical industries depending upon coal-tar, for example, explosives form one of many groups of fine chemicals, including dyes and drugs. These are so closely interlocked that a member of one group is often a by-product in the preparation of a member of another group. So, in the war of 1914–1918, Great Britain was sorely handicapped in producing explosives because of the lack of a strong organic chemical industry, and a corresponding dearth of skilled organic

chemists. After the war, the position was safeguarded by a Dyestuffs Act, which prevented Germany from resuming her old practice of dominating the British fine-chemical market by underselling. It says little for the public appreciation of scientific problems in Great Britain that the renewal of this Act hung by a thread in 1937—a little more than two years before the start of a new war by Germany.

In the popular mind, explosives mean solely the propulsion of missiles, the bursting of bombs and shells, and destructive activities in general. Let us remember, however, that besides their destructive abuses in war, explosives have constructive uses of the highest value in peace. Many vital industrial and engineering operations would be impossible without their aid. In peace-time such civil activities as quarrying, mining, tunnelling, and the construction of roads and railways utilize explosives in hundreds of thousands of tons every year. Under proper control, explosives have an unrivalled capacity for doing useful work, as we may see in such wonderful constructions as the Simplon Tunnel and the Panama Canal. Economic, political, and even geographical considerations are clearly bound up with such achievements.

Think of the revolution accomplished in the excavation and removal of rock through the use of blasting explosives! Formerly this was done painfully by hand, with hammer and chisel, supplemented by "fire-setting," or splitting and flaking the rock by means of fire and cold water. Think again of the impossibility of mining coal for modern needs without the help of explosives! Consider, too, the incessant research providing ever safer explosives for this purpose.

It has sometimes been urged that we should abandon explosives and explosives research, because man has misapplied the discoveries. This position is untenable. Apart from the difficulty of securing international agreement in such a matter, there is an inherent urge in the human mind "to follow knowledge like a sinking star." It is no more possible to ban scientific research than to forbid exploration, mountaineering, or crossword puzzles. Remem-

ber also the inter-relations of explosives: coal-tar constituents are the common parents of TNT, lyddite, saccharin, synthetic indigo, salvarsan, and M. & B. 693. Even a controlled production of "key" chemicals—such as ammonia, nitric acid, and sulphuric acid—used in making explosives, is complicated by their position as "key" chemicals in numerous essential industries, including agriculture.

Scientists naturally deplore, even more than others, the perversion of their own discoveries and the debasement of their work and genius. Listen to the eighteenth-century Dutch scientist, Boerhaave, the most famous physician, the foremost chemist, and the most erudite scholar of his day. The art of war, he observed in 1732, has turned entirely upon the one chemical invention of gunpowder. "God grant," he added, "that mortal men may not be so ingenious at their own art, as to pervert a profitable science any longer to such horrible uses."

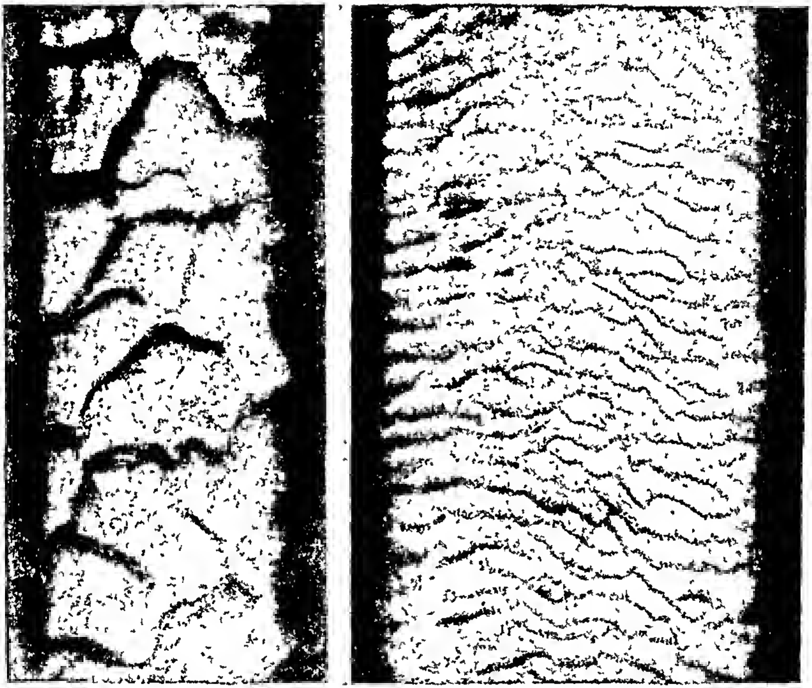
When man discovered fire, he took into his keeping an instrument with unbounded possibilities for good—or evil. Fire, says the old proverb, is a good servant but a bad master. But we have not banned the use of fire because a cigarette-end thrown carelessly into a rickyard may destroy a whole harvest. Explosives are a refined form of fire.

Let us end where we began, at that instructive horse-pond. Beside it stood the village smithy. "Your fire's out!" I said one day to my friend the smith. He stroked the long bellows-handle caressingly, and a glow soon appeared in the embers. "Out, is ur?" said the smith, "Why, zonny, there's vire enough in he vur to burn down all London!" Whereupon he thrust an unfinished horseshoe into the midst of the glow.

"The fault, dear Brutus, is not in our stars, but in ourselves."

This being so, may we not look forward to an enlightened age, in which the discoveries of science will be used entirely for the benefit of mankind?

It is worth our while to consider what practical measures we can take to realize this ideal.



Surface structure of (*left*) wool, magnification 800, and (*right*) human hair near the root, magnification 500

Berthold Schwarz in his laboratory
(*From a copper engraving by R. Custos, 1643*)

SOUNDING THE EARTH'S CRUST

By Dr. A. O. Rankine, O.B.E., F.R.S., Chief Physicist of the Anglo-Iranian Oil Co.

When gold was discovered in Australia, sizeable lumps of it were frequently found exposed on the earth's surface. They say even now in Bendigo that after rain you can pick up in the neighbourhood of a pound's worth of gold particles —if you're lucky and patient enough to spend a day at it. In Persia—or Iran as it's now called—I've seen the natives filling their vessels from a little pool fed by a bubbling spring. But it wasn't water they drew; it was oil—white oil—fit without refining to put in their lamps. Everyone knows, too, that some of our coal is won from surface workings where it lies exposed to view and is dug up almost as one quarries chalk or sand.

But such easy finding is rare. The treasures of the earth are mostly buried beneath the surface, often at great depth. Some mines are nearly a mile deep, and oil has recently been obtained from holes bored close on three miles into the earth's crust. The question is, how can we tell where they are. What other means besides seeing are there for locating these hidden riches, so that they may be extracted from the earth with a minimum of effort? Every unsuccessful boring—a "dry" hole as we call it in oil prospecting—means waste of materials, and often many months of fruitless labour. That is where the geologist and the geophysicist come in.

What I have to say has nothing to do with divining as commonly understood. The methods we geophysicists employ depend upon well-established physical principles.

Generally speaking, the closer you are to a thing the more

likely you are to find it. This is true of search by geophysical instruments; when they're near what is being looked for they can give reliable indications of the objects sought. When they're not near enough they can't help at all. In fact, geophysical instruments have a restricted range. It would be quite impracticable, for example, to use them to locate oil-bearing rocks without any previous guidance as to the areas within which those rocks are likely to be. We must first get help in choosing areas worth examining geophysically, and we get this guidance from the geologist who is, in fact, the precursor of the geophysicist. Geological studies of the composition of rocks and the way in which they lie in the earth's crust enable the geologist to select in many cases comparatively small regions under which the mineral sought probably lies. In his task he relies largely on the fact that the sequence of rock beds or strata which constitute the terrestrial shell do not lie everywhere horizontally. They have in years long past been bent or folded into mountains and valleys, and thereafter worn away where prominent so that rocks elsewhere deeply buried are exposed to view and scrutiny. The nature of these outcropping beds, particularly the manner in which they slope, helps the geologist to predict how they extend underground. But as the distance from the outcrop increases, the more vague becomes the geologist's picture of the underground structure. It's here that the task of the geophysicist begins. He has to survey the neighbourhood with instruments so as to define the structure more precisely and thereby fix the points where drilling or digging should start to reach the buried objective. This collaboration between the geologist and geophysicist is truly a combined operation, and the more likely to succeed the firmer it is.

How then does the geophysicist play his part? Fundamentally, he has got to rely on the thing which he seeks being in some way *different* from the rock beds which cover it. Suppose that the search is for oil deep down. In this case

it proves to be impracticable to make use of the special physical properties of the oil itself; but geological experience indicates that certain rock beds, such as limestone, are likely to be impregnated with oil if they are humped upwards, so as to form, as it were, an underground hill. The problem thus becomes one of locating the summit of this buried limestone hump. There are two physical methods of doing this by observation carried out on the earth's surface.

The basis of the first method is the force of gravity. We are all familiar with this force; we've learnt to attribute the pull downwards that we feel when we support a weight to the attraction the earth exerts upon it. But do we realize that every portion of the earth, even the smallest, contributes its part to this force, to an extent depending upon how much there is of it and how far it is away? Dense rocks also exercise at the same distance a greater attraction than those less dense. Now limestone is usually denser than the geological strata overlying it; hence volume for volume it exerts greater gravitational force. Thus if we were to carry a weight over a buried limestone anticline—one of these humps, as I've called them—it would get heavier as we approached the summit of the hump and lose weight again after passing over it.

I'm not suggesting that this is the actual method of procedure. The variations of force in question are far too small to be felt in this way. Our sensation of pull is, indeed, particularly crude, and some much more delicate means of observation must be found. Even our much more powerful sense of vision sometimes requires instrumental aid, as when we use telescopes or microscopes. For accurate perception of force, here with greater necessity, we have to employ special forms of apparatus, called gravity meters. These gravity meters depend generally upon the twisting, bending, or alteration of length of fine metal wire or delicate springs suitably loaded, under the influence of gravitational changes. They have the requisite sensitiveness, but are nevertheless

robustly made; they have to be, so as to stand up to the rough usage inevitable in field operations. The best of them will measure changes in gravity of less than one part in ten million—about equivalent to one more drop of water in your already full bath. I have now vividly in mind two remarkable gravity meters which I saw being operated a few years ago in the State of Kuwait on the Persian Gulf. In the course of only seven months the whole of Kuwait's five thousand square miles—about the size of Yorkshire—was surveyed in great detail. And the gravity picture thus obtained helped a lot in fixing the location of highly productive oil wells sunk subsequently in that country.

It mustn't be supposed that the gravitational method is limited to the mapping of *limestone* underground. Under suitable conditions it can be applied, whenever the object sought is *different* in density—whether less or more—from the things that surround it. The method has indeed achieved its greatest success in the United States, where, under the plains around the Gulf of Mexico, numerous domes of rock salt, with which oil is associated, have been located.

But difficulties arise when the surface of the region to be surveyed is rough and hilly. The hills themselves exert gravitational forces which may be large enough to mask the feebler forces due to the underground irregularities. In these circumstances one has to turn to an alternative method—the second I shall describe, which has, in fact, been much more widely used. It's called the seismic method, or, if you like, the "earth-shaking" method.

To illustrate it, think again of a potentially oil-bearing limestone anticline like those occurring in Iran. The difference as between limestone and its overlying beds upon which this "earth-shaking" method depends is not now that of density, but what, for want of a better colloquial term, I shall call hardness. The limestone is harder than the strata above it; consequently, in spite of its somewhat greater density, mechanical shocks travel through it faster than they

do through the overburden. Moreover, this same difference of hardness causes shocks coming from above to be partially reflected at the surface of the limestone. Either or both these phenomena may be made use of by those practising seismic prospecting. They have to be equipped with very delicate seismometers, which are also robust and portable. These instruments record earth tremors and the times at which they reach the points of observation. To create the tremors, charges of dynamite are exploded in the earth's surface at suitable places. As regards both the measurements of time and what is deduced therefrom, seismic prospecting resembles closely the better known subject of seismology—the study of the internal structure of the earth as a whole by means of the tremors originating in natural earthquakes. Only our earthquakes are very much in miniature, besides being started just when and where we want them by exploding anything from a few pounds to several tons of gelignite.

The particular procedure most commonly employed, and the easiest to describe, is to observe what are in effect echoes; only it is the seismometers, and not our ears, that "hear" them and measure the time elapsing between the instant of the explosion and the arrival of the echo. The velocity of the tremors in the overlying beds being known from suitable measurements, the depths of our limestone at any chosen points can be found by simple calculation, and its shape thus disclosed. It's by no means always so straightforward as this. Often there are complications due to multiple reflections from other beds, and great skill is needed in the interpretations of the seismograms—seismograms, that's what the records produced by the seismometers are called. The method fails not infrequently, but it succeeds, too, often enough for it to be regarded by progressive oil companies in the United States as an essential preliminary to boring for oil. The same is true of the extensive operations by oil companies in this country as well as Iran, where seismic prospecting of a somewhat different type, based upon the

refraction instead of the reflection of the seismic waves, has been practised with considerable success.

Geophysical prospecting is a comparatively new application of science; it began to be practised on a notable scale less than twenty-five years ago. Although now in great vogue, its surveys are done chiefly in regions sparsely populated; consequently, its direct effects on everyday life are not much noticed. Where the surveys do encroach on human habitations they do make their presence felt—quite literally if the method used is the seismic one. The exploding charges cause some slight damage to crops and occasionally to livestock; but the compensation paid by the prospecting party is usually more than adequate. Some claims, of course, have to be rejected, as when the injury is said to be the reluctance of hens to lay, owing to fear of our little earthquakes. On the positive side, although it is as yet no great matter, it may be recorded that the visit of a prospecting party nearly always provides employment for local workmen, who are needed to assist the geophysicists in their field operations.

But it is not this direct effect upon human life that deserves emphasis. We should consider rather the question of ultimate utility, and ask whether this sounding of the earth's crust has contributed to our well-being, through the produce of the earth which it helps to make available to mankind.

I have confined my remarks in this talk mainly to the search for oil, and said little about other minerals, partly because I know more about oil, but also for the reason that I wanted to answer in the affirmative the question just posed. Without geophysical prospecting we should either be suffering now from a world shortage of oil, quite apart from war-time restrictions, or at least have to face scarcity before long. The dangers of this situation have been realized by oil producers generally, and money measured in millions of pounds has already been spent on geophysical work, particularly in the United States, the source at present

of most of the world's oil supply. Moreover, extensive and intensive geophysical campaigns have been initiated in many other countries hitherto untapped, in regions geologically suitable for such examination. It's reasonably certain that much more oil lies hidden in the earth than has been taken out of it—a trifle of less than two cubic miles—and geophysics is sure to go on helping to make it available.

And if crude oil as it comes from the wells is in copious and increasing supply, so also will be the useful things derived from it—petrol, synthetic rubber and plastics, to mention only a few of many.

As to minerals other than oil, such as the ores of iron, copper and lead, there has been so far relatively little demand for the help of physics in searching for them. Appropriate methods have, none the less, been developed quietly and form, as it were, weapons in reserve. They depend upon the marked magnetic and electrical properties of these ores. If these so-called base, but most useful, metals should threaten to become scarce, the geophysicists, newly-equipped, may be called again in strength to the prospecting front, and may be expected to give an equally good account of themselves.

We've been thinking of finding minerals—a matter not easy to discuss without some technical knowledge. What to do with them when found is of more general interest. Perhaps you may care to consider this, remembering how very different in political development are the countries in which the minerals are found, and try to answer the question—What organization of distribution and use would conduce most to the general benefit of mankind?

OUR WEATHER

By Sir Nelson Johnson, K.C.B.,
Director of the Meteorological Office

"Here is the Air Ministry's weather forecast for to-morrow. There will be occasional rain in most districts, but also bright intervals. Thunder will occur locally. It will continue rather warm."

That was the last forecast issued by the B.B.C before the outbreak of war. In those care-free days, most of you thought of the weather in terms of its effect upon your garden, or the Test Match, or in the case of air travellers that flight you were making to Paris.

If you ask the Air Ministry for a weather forecast now you won't get one—indeed, they will tell you practically nothing about the weather.

We all know, of course, that weather forecasts are of importance for war purposes—particularly for the R.A.F., but I think it may be interesting to see in just what ways the weather affects flying operations. So let us follow the day's work of some of the meteorological officers in Bomber Command.

First thing in the morning the Commander-in-Chief at Headquarters, Bomber Command, sends for his Senior Meteorological Officer to learn the general weather situation and to select the night's target accordingly: The selection may be a provisional one, because at that time there may be some uncertainty about the exact weather to be expected eighteen hours later at a place possibly six hundred miles away.

By the afternoon further weather reports have come in, and make it possible to be more precise. The Senior Meteoro-

logical Officer at Headquarters now gets into touch with the Senior Meteorological Officers at all the groups in Bomber Command which are to take part in the operation, and they proceed to hold a "telephone conference." In this way the opinions of all these experts are pooled, and the Commander-in-Chief and the various Group Commanders can be presented with an "agreed" forecast. And on the strength of this forecast the operation is either confirmed or cancelled.

What factors do the meteorological officers have to take into account when making their forecast? The weather on the route to the target must be favourable—in particular there must be no undue risk of severe "icing" of the aircraft. On reaching the target area, the pilots must be able to see their objective clearly—it must not be hidden either by a layer of cloud or a blanket of fog or haze lying on the ground. Last, but by no means least, when the aircraft reach home again, the pilots must be able to find their aerodromes still free from low cloud and fog so that, exhausted themselves and possibly with a damaged aircraft, they can land with the minimum of difficulty.

If the operation is "on," the meteorological staff at each of the groups must then work out their own details—the wind and the weather which their own aircraft will meet on the way to the target, and the weather changes which are likely to take place at their own base aerodromes by the time the aircraft are due back.

Shortly before take-off, the pilots and navigators are given the latest and most accurate advice possible. This briefing, as it is called, is carried out by the meteorological officers at the actual bomber stations. They explain the weather situation in detail so that the air crews can act with a full understanding of the weather changes they are going to meet. Questions are asked and answered to clear up any doubtful points. Now and again the briefing officer may be able to say: "I think you will be home early; it looks as

though you will come in for a tail wind on the return trip."

But the meteorologist's task isn't finished when the aircraft have been despatched. He must see them landed safely back at their bases again. He must continue to watch the weather minutely throughout the night to see that it is going according to plan. If, by chance, early morning fog begins to form at some aerodromes earlier than expected, he has to make rapid decisions as to which aerodromes will remain "open" and for how long, so that aircraft whose aerodromes have gone "out", as we call it, may be directed to safety.

And when you remember that a bomber operation may involve nearly a thousand aircraft with some 5,000 men inside them, you will, I think, agree that the meteorological officer carries a big load of responsibility.

We chose for our example a bomber operation, but the same type of procedure is followed for all flying operations—whether it be the anti-submarine patrols of Coastal Command, or the daylight sweeps and night "intruder" operations of Fighter Command, or the trans-Atlantic flights of Transport Command, Indeed, it is safe to say that no flight is undertaken without due regard to the weather. And if a flight has to be made in spite of the weather, knowledge of how it is going to change may be of tremendous importance—both to the success of the operation and the safety of the air crew.

By what ways and means does the meteorological officer make his forecast for these purposes?

To make a forecast it is necessary to draw a weather map similar to those which were published in some of the daily newspapers before the war. But the forecaster's working chart is, of course, very much larger—about as big as a fully opened newspaper—and it covers a very wide area—most of Europe, the Atlantic Ocean and possibly North America too. Before the war there was no difficulty at all in covering the chart with weather reports because, by international arrangement every country broadcast its own

reports for the benefit of every other nation. Numerous ships sent reports from the Atlantic and these were of special importance. The reason for the importance of these ships' reports is that, broadly speaking, most weather systems travel from west to east, so that to-morrow's weather in England is frequently decided by the type of weather out over the Atlantic to-day.

But with the outbreak of war the peace-time arrangements went by the board. The countries at war, and some neutrals, too, stopped broadcasting their reports, and wireless silence was immediately imposed on all ships at sea. As a result the forecasters found themselves with huge blank spaces on their charts, and it became necessary to devise new methods of obtaining information for making reliable forecasts.

In passing, it is worth noticing that the fact that weather travels from west to east makes it particularly important to prevent the Germans from knowing the weather condition in the British Isles, since it would give them an invaluable guide to the weather they could expect. That is why we put such a strict ban on our weather information. But to return.

The first and most obvious way of getting extra information is to arrange for R.A.F. aircraft when engaged upon operations to make and bring back weather reports. Bombers attacking Berlin or any other targets on the Continent do this, and bring back reports of the weather they have encountered, which are of the greatest value in forecasting the conditions to be expected over Germany the following day. In the same way, Coastal Command aircraft hunting submarines out in the Atlantic, and Transport Command machines flying over from North America, tell us what depressions and "fronts" are advancing upon the British Isles from the west. The zeal shown by the R.A.F. air crews in making these observations, when they already have a thousand and one other things to attend to, is beyond all praise.

But there are certain regions which are not visited sufficiently regularly by ordinary aircraft, and to cover these, special weather patrols are made. Specially trained pilots and observers go out every day—whatever the weather—in aircraft fitted with meteorological instruments. They fly long distances into remote areas stretching from the Arctic to the Azores and bring back most valuable weather reports. Any U-boat or Ju. 88's which they encounter are taken in their stride as part of the day's work.

To help you understand the next two points I am going to mention, let me remind you that the atmosphere is not just a shallow layer close to the ground—it extends upwards to great heights. And so we cannot obtain a complete picture of what is taking place if we have observations only of the conditions near the ground. Indeed, it has been clear for some time past that we shall never get to understand the weather properly until we have sufficient reports from the upper regions. It is in this direction that progress is to be looked for.

The most obvious way of finding out the pressure and temperature and humidity of the upper air is by going up in an aeroplane and measuring these things with the proper instruments. The R.A.F. have been doing this regularly for several years now, and they bring back as well reports on the clouds which they have met on the way up and down. All this information is of the greatest importance to the forecaster in working out the type of weather to be expected for to-night's or to-morrow's operation.

But there is a more modern method of doing the same thing more quickly and more cheaply. In this method we send up a free balloon about six feet high carrying a special instrument called a radio-sonde. This instrument measures the pressure and temperature and humidity of the air as the balloon rises, and then automatically sends out radio signals of the readings it has made. All the observer has to do is to sit beside a radio receiver in his office and receive *immediate*

reports of the weather conditions all the way up to ten or twelve miles high. And since the balloon is carried by the wind as it rises, the observer—a different man in this case—can also measure the speed and direction of the wind all the way up if he "follows" the balloon with a wireless direction finder. And when, in due course, the balloon bursts, a parachute opens and the radio-sonde floats down to earth again. Each instrument carries a label telling the finder how to return it to the Air Ministry and offering him a reward of five shillings for his trouble. After slight adjustment the radio-sonde can then be used again to play its part in winning the war.

The Germans are also using instruments of this kind but the wording on their labels is rather different. Instead of offering the finder a reward, it threatens him with dire penalties if he fails to comply with the orders it gives him. The Hun runs true to type, even in little things!

So far we have been thinking about the weather mainly as it affects the R.A.F. But the other fighting services need weather information too. Every anti-aircraft gunner must know what winds and other conditions his shells are going to encounter, and he must make the proper allowances for them if he hopes to hit his target. The same is true of the other kinds of guns the army uses.

Sometimes the Army try to locate the position of an enemy gun by what is called "sound-ranging." The method is similar to measuring the distance of a thunderstorm by noting the time between the lightning flash and the thunder. In this case you calculate the distance of the enemy gun by measuring the time between the flash and the bang. But to fix the gun position accurately, you must make the proper corrections for wind and other weather conditions.

The weather also plays an important part in the use of smoke screens. Indeed, it may decide whether a smoke screen can, or cannot be produced to cover a *particular* military operation.

The Navy, too, has its own special weather problems which are dealt with by its own meteorological organization.

Let us now forget about the war and look ahead to see what part weather knowledge will play when we return to peace.

Does anyone doubt the importance of civil aviation in the post-war era? Will not the bombers and reconnaissance aircraft which now fly such long distances over the continents and oceans give place to giant air liners flying over greater distances? Such methods of conveying passengers, mail and freight have come to stay, but their operation will not be possible without the weather service.

At the outbreak of the present war short distance civil aviation within the British Isles was just beginning to get into its stride. As soon as men and machines become available it will go ahead again.

Those of you who travel by these means may rest assured that your pilots and navigators will be supplied with the best weather information that experience and modern developments can provide.

There are many other ways in which weather affects us all—directly or indirectly. Climatic statistics are needed for town planning, and rainfall data are required by the water supply undertakings. The sites for civil aerodromes cannot be selected without knowing the frequency of low cloud and fog, whilst the lay-out of the runways must be planned in the light of the local prevailing wind directions.

The knowledge of future weather, and particularly spells of settled weather, is of great value to the farmer in deciding when to sow, reap or carry. Gale warnings protect our shipping. Forecasts can also be made of when the Thames is liable to overflow its banks so that steps may be taken by the authorities to prevent danger to human life. By anticipating snow and what is called "glazed frost," action can be taken in advance to keep the railways and roads open when otherwise serious dislocation of traffic would be bound

to occur. The large electricity undertakings can be warned when thunderstorms are expected and precautions taken to protect their systems from the effects of lightning. These are some of the uses to which weather forecasts are already put.

Many business undertakings are beginning to realize that the economy and efficiency of their concerns can be increased by taking account of the weather elements, and we may feel sure that the return to peace will discover new directions in which weather knowledge can be placed at the service of the community.

THE HOUSEWIFE AND THE FISHERIES

By Michael Graham, Fishery Scientist, author of *The Fish Gate* and *Soil and Sense*

For several years now, I have been anxious about the power of the housewife's shopping basket, which has increased so much with modern development of transport. There was a time when food mainly came from close to the house; for example, cows were kept in London itself. Alternatively, the housewife of those days bought fully preserved food, like salt beef.

But nowadays, in peace-time, a housewife can buy the second-best from any part of the world—and only a little stale at that. This modern development has made life precarious for the producers of fresh food; for example, the shepherds of the Downs, whose large sheep gave joints that were not as convenient for small households as those from the grazing type of sheep common in New Zealand.

Fish provides another example. To the housewife, in peace-time, fish is a small part of the menu—hardly noticed one way or the other; and in war-time it is so badly wanted that prices rise to quite foolish heights. But fish to a fishery scientist is mainly a problem of population—populations of fish—to be solved by some of the simpler mathematics.

I can make this clear by summarizing the history of modern trawling: at first, and for nearly a hundred years, fishing produced more fish from near waters by exerting more and more fishing power: more vessels, and larger and faster ones. Finally, in the North Sea, we have been taking every year about two-thirds of the average stock (young fish, of course, grow up to replace those caught).

Two-thirds of the stock every year is a large proportion,

and many people do not know that fishing operations dig so deep into this natural resource. It is therefore worth looking at the evidence for my statement.

Firstly, as to the quantity caught, it should be explained that there are very good statistics of the weight of the catch for many years past—since 1906. Collecting and tabulating them has been a very big task; but there is no doubt of its success. Thanks to conscientious and critical service, by devoted civil servants, the statistics are right to within a few per cent.

Naturally, it is more difficult to estimate the weight of fish in the sea; and if this can be done within 20 or 30 per cent, it is something of a triumph. For one stock of fish, the plaice of the North Sea, we have two independent methods.

One way is to count the eggs. The plaice gather to spawn in the southern North Sea just after Christmas each year, and their eggs float up to the surface, 250,000 from each female plaice. By sampling the area regularly during the season, with a silk net that filters a known volume of water, it is possible to estimate the total number of eggs. This can be used to give the total number of spawners, and, knowing the proportion of mature to immature, the total number of plaice of fishable size. The answer comes to 300,000,000—in a good year.

The other way of estimating the number of plaice in the sea is to mark the fish and let them go again, and then find what proportion of the marked fish are returned in the catch. About 17,000 plaice were marked between 1900 and 1914, and about 5,000 marks were returned to fishery officers. But, of course, many marks were shed before the fish were caught, and others were kept by the fishermen, or lost. It is possible to estimate these losses reasonably well, and make adjustments that I need not enter into here. The result of this estimate was that the average stock was 210,000,000 fishable plaice. Taking into consideration that this is an average figure over many years, whereas the other was a

figure for a good year, the two answers are in good enough agreement.

So the stock is known, and the catch is known, and the ratio of two-thirds, found in one method, is confirmed by the other.

Another kind of evidence, on the large proportion of the stock caught by trawling, comes from war experience. During the years 1914–1918 there was very little fishing in the North Sea, and, when we came to examine what happened as a result, we found that the weight caught per unit of fishing effort in 1919 was about twice that of 1913, taking comparable areas, and efforts. In this war, too, the catches of the few vessels left fishing round the edges of the North Sea have greatly increased; and, in addition, some Danish fishermen, captured on the Dogger Bank in 1943, reported to the Press that they could fill their vessels in half the time that they needed in peace-time. The effect of stopping fishing has been phenomenal in both periods.

Turning now to the commercial aspect—the effect of this severe trawling on the profits of the industry—we have clear and unassailable evidence from the report of the Sea Fish Commission of 1936 that the profit was driven out of the business. From the very careful analysis of accounts it was shown that Near Waters trawling was literally unprofitable, although many men stayed on in it in hopes of better times. The better times never came.

The explanation of this chronic lack of profit has been proved to be a simple one—that the fish were not allowed time to grow to any size. Now the war has allowed them to grow again. A great deal of research has gone to prove that moderated fishing would always allow them to grow to a reasonable size—when they would be heavy enough on the average to give the fishermen a fair living. The size would also be better for trade, and for the housewives. To sum up the lesson of fifty years' research work: until there is moderated trawling there will not be a good regular supply of fresh

haddocks, cod, plaice, and hake. This is a serious matter in many respects. The fish are needed, especially by old people, by invalids, and by children; and the country has another interest as well, namely a steady fishing industry and a flourishing population of fishermen.

So far I have been dealing with the overfished stocks of trawled fish in Near Waters, but there are other fisheries whose state at present is essentially different, and it is in these that the power of the market—that is, the housewife's shopping basket—is seen most clearly.

Thus, turning to the herring fishery, there are millions and millions of herring, and catching them at the rate of a thousand million a year, as we did once, did not disastrously reduce the stock, so far as could be told by science; although it did, we think, make large herring somewhat scarcer. Herrings are of many races or tribes, and some herrings can be caught, in one or another locality round the British Isles, at any time of the year. But the greatest concentration in the world—of the best quality for inland trade or export—takes place in October and November only thirty to fifty miles away from the coast of Norfolk. This concentration is a remarkable natural resource, the wealth of which is borne in on anyone who has taken part in the fishery.

One day stands out vividly in my memory. The men started to haul the nets at four o'clock in the morning. They had looked at the first net or two and estimated that the catch of all the nets would amount to 100,000 herrings; in their own words, they had had a "look on" at the first net or two, in the darkness, seeing the flash of the herrings silvery sides in the lamplight; and had decided that there was a "hundred cran shimmer." So the word had gone to all hands to haul the nets. But at daybreak, when only a small part of the nets were hauled, the fish struck again; and by ten o'clock in the morning, we, and all our neighbours round us, knew that we had a tremendous catch. The fishermen in other craft judged by the time it was taking our ship to crawl slowly

up the line of nets as we gathered them in. They also saw the great flurry of gulls round us, and about a score of gannets working our fish. The gannets circled 100 feet up in the air; chose their fish from one of the many beating away from the net below the surface; and then dived, squawking at the gulls to drive them out of the way, as they came down in the dive with their wings tense-shouldered for the shock of the water. Below the ship, too, the hunt was on. We could see the gladiator whales turning and swerving below us as they seized the dying herrings.

For us, excitement was suppressed by toil. The net was hauled and shaken, hour after hour, to the limits of human fatigue. Herring scales seemed to fly like sawdust; herrings were in the scuppers, on the engine casing, under our feet everywhere as we trod.

At noon our nets would come no more. The herrings had died in them, unable to work their gills, and the weight of dead fish had taken the nets down to foul some obstruction on the bed of the sea. So we had to cut; and another craft, not encumbered by any catch of her own, took over the task of lifting our abandoned nets, and their fish, starting from the other end of the line of nets.

Our crew worked for twenty-four hours, with only half an hour's break for tea, before they finished landing that catch. But it was the best of the season; and against it must be set many nights when we fished and caught nothing.

Herring, they say, at half a crown a pound, would be esteemed above salmon; and there is doubtless some truth in that. Cheapness, very naturally, can obscure the recognition of quality. Quality in food cannot easily be defined by scientific analysis, but fish is at last beginning to be recognized as "first class protein," and a herring is among the best of fishes. It is, however, much neglected. If everyone ate one herring or kipper once a week during the first half of the year, and thrice a week from Midsummer to Christmas, which by good natural arrangement is the season when

eggs are scarce and dear, there would be no problem in the herring fishery. The price would have to be about $1\frac{1}{2}$d. per fish. There would be a surplus in October and November, but our foreign trade could easily handle that.

Instead, our herring fishermen worked, for many years in the Dreary Thirties, for less than a pound a week. About half of them gave up altogether. Doubtless, herrings were rather smelly to cook in small households; doubtless, there are too many bones for hurried eating; and the herring does not come in a pretty package with a coloured wrapper. When, for other reasons, our export trade in herrings shrank disastrously, it is a pity that these other, petty, difficulties in the home trade prevented it saving for us the men and the ships that the Admiralty needed so badly in this war.

Another large fishery, which was not exhausted in pre-war fishing, was that for cod in the Arctic. There were undoubtedly thousands of millions of them, inhabiting many northern seas, but especially those round Iceland, Norway, Spitzbergen, and over to Nova Zembla. Those grounds are a long way away, and, unfortunately, by the time the cod reached England they were stale. For my part, I would not pay 4d. per lb. for them.

But cod was just cod, and money for food was tight, and because these stale cod, in their vast quantities, could be sold at the quay for half a crown a stone, really fresh cod from the North Sea and Faroes, had to fall in price, too.

Refrigeration was tried in the Arctic ships, but when this, decently fresh, cod went into the trade, it was just cod, and the cost of refrigeration was not recouped. It would have been necessary for shoppers to have known of this fresher cod, and to have been willing to pay a little more for it.

I write of fisheries because of their intrinsic interest, but, as my studies have progressed, I have found several things, "laws" we should call them in the scientific world, that seem to me to apply generally. One of them is the power of the shopping basket, to which the study of the Arctic cod

fisheries has brought me back again. It is my idea that a very large proportion of the money that is spent by individual people is spent by women shopping. Consequently, it may not be an exaggeration to say that the greatest power in the world is the hand that fills the shopping basket. Every week the men hand that power over to the women, in the form of housekeeping money. If that much is true, or even somewhat true, we have a power here that can make or mar any plans for reconstruction; and we therefore have to beg women to be discriminating in their housewifery, and critical, and industrious—as some women have been in every generation.

The women appear to be the real masters, at whose bidding men mine the earth, and till the land, and fish the seas.

If it is true that the earth's natural resources can only be rightly used if women direct their shopping to that end; then I wonder how the world's needs can be made known, and thoroughly understood, and established, so that some at least of the shoppers may know what they are about.

I cannot give the answer to that; and I cannot decently press my own view, which is that science can help here.

The late Professor Karl Pearson wrote a book called *The Grammar of Science*, of which I have always liked the introductory chapter. "We must carefully guard ourselves," he wrote, "against supposing that the scientific frame of mind is a peculiarity of the professional scientist." This frame of mind includes "the insight into method, and the habit of dispassionate investigation," which "give the mind an invaluable power" of dealing with facts, as the occasion arises.

But he warns us against making too great a claim. "I am only praising the scientific habit of mind," which, he writes, will enable a scientist to judge in other fields, according as he has classified and appreciated his facts, and been guided by them and not by personal feeling and bias in his judgments.

Other contributors to this series have recounted the many services of science in technical aids and devices for better living. It seems to me that there is something to add. To my mind, science, properly used, could render society a supreme service, if it could engender a scientific attitude to the common problems of life.

SAVING LIFE AT SEA

By DR. ALBERT PARKER, Director of Fuel Research

IN the year 1912, two years before the last Great War, the wreck of British ships at sea caused the loss of more than 2,300 lives. 1912—that was the year which included the heart-rending loss of the *Titanic*, when 1,500 passengers and crew went down. Since that time, in the short space of thirty years, science has made discoveries which have greatly reduced the hazards of shipwreck in the vast ocean expanses. I need only remind you of the developments in radio and other ways of signalling, whereby those in distress can indicate their position to ships over distances of many miles. Then we have the modern aeroplane, which travels at such great speed, that it can rapidly search enormous areas. In consequence, the risks at sea, in normal times of peace, are now very small compared with what they were thirty or forty years ago, when rescue depended largely on the chance of being sighted by some ship passing nearby.

But it isn't always realized what science has done, and is doing, in improving the design of life-boats, and in lessening the discomfort of the occupants until help arrives.

What are the primary material needs of man? They are air to breathe, water to drink, food to eat, and warmth, clothing and shelter to protect him from the elements. Of these, air and water are of the first importance. It's well known that a man can live for several weeks without food, but he cannot live for more than a few days without water.

We in Great Britain, who have never been desperately short of water, cannot realize what real thirst means. But you ask the desert soldier who has been lost from his unit!

You ask the seaman who has been torpedoed and adrift for weeks! Some of those intrepid sailors have been shipwrecked more than once; they know what privation means.

During these war years, the problems of saving life at sea have received great attention in several quarters. As a result, important improvements have been made in life-saving devices. How best to provide drinking water has been specially studied by the Department of Scientific and Industrial Research, in co-operation with the Ministry of War Transport, the Medical Research Council, and industry. It is because it has been my job to lead a team of scientists in finding how best to make drinking water from sea-water, that I have been asked to talk to you to-night.

In tackling the problem of getting drinking water for life-boats, we must first know how much water each man needs a day and for how many days. In a temperate climate like that in this country, the average quantity of water taken in one form or another by an adult is roughly two-and-a-half pints a day. It is known, however, that much smaller quantities will maintain life for many weeks. If we set the high standard of say one pint a day for four weeks, 140 gallons would be required for a life-boat for forty people. It's not at present practicable to allow space in a crowded life-boat for 140 gallons of stored water, with all the other vital equipment.

Before the war, such a life-boat was provided with ten gallons of stored drinking water; but in peace-time, when ships follow recognized sea lanes, help usually arrives within a few hours or days. In war-time, help may be longer delayed, and it is now the practice to supply nearly thirty gallons of stored water, equivalent to nearly a quarter of a pint a day for each person for four weeks. This improvement has been made by skilful re-arrangement of the inside of the boat, and the stowage—an intricate problem to which much thought has been given. In wet weather the supply can be supplemented by collecting rain water. A fabric

rain-catcher has been designed by the Ministry of War Transport. When rolled up for packing, the rain catcher is little more than a foot long and is only a few inches wide. When extended and tied down, it catches rain over an area of about six square yards. With heavy rain, twenty-five gallons can be collected in a few hours. But there is not always rain, and when there is none, something more is needed.

You may well ask why men should be short of drinking water, when they are surrounded by billions of gallons of sea-water? Unfortunately, sea-water isn't fit for drinking because it contains so much dissolved salt. It is, in fact, dangerous to drink sea-water, unless you also take a large proportion of other water containing little or no salt.

What is the amount of salt in sea-water and what is its nature? Over many years, there has been continuous scientific investigation of the waters of the open sea. In this work, which has been organized internationally, Admiralty and other British scientists have played a great part.

Sea-water contains a mixture of salts and it has been shown that four fifths of the mixture is the same as common salt used for cooking. Broadly speaking, the amount of salt in sea-water is between 3 per cent and 4 per cent. This amount is about four times as great as the salt in the human system and mainly explains the harmful effect of drinking only sea-water. To most people, water containing only one-tenth of the amount of salt in sea-water would taste horribly salty.

What is needed in emergency at sea, is some easy method of removing the salt from sea-water to give drinking water. There are several ways of doing this, but they are mostly difficult to operate. The most obvious way is distillation, that is to boil the sea-water and condense the steam. It is also known that when sea-water is cooled to freezing-point, the ice which first separates contains very little salt, because most of the salt remains dissolved in the water not yet

frozen. But there are other ways. By adding certain chemicals, the salts can be separated as solids which can be removed by filtering the water; this method is complicated and uncertain unless very carefully controlled. Nearly ten years ago, it was found by British chemists that certain synthetic resins can take the salts out of sea-water. These resins belong to the class of substances known as plastics, which are described by Sir Lawrence Bragg in Chapter 3. By this method, the sea-water flows through granules of one kind of resin, and then through granules of another kind. The action of these resins is similar to that of the material in ordinary household water softeners, but they do a lot more. Unfortunately, the volume of drinking water obtained in this way from sea-water is not much greater than the volume occupied by the resins themselves, unless the resins are treated frequently with acid and alkali. There are other methods of removing salt, but they are very involved.

From recent work, it has been concluded that the two most promising ways are distillation, and a combination of chemical treatment with a method similar to that using resins. After numerous experiments, distillation has been selected as the best for life-boats.

It's not so easy as it may seem to design a small still for life-boats, as several important conditions must be met. The space occupied by the still and fuel must be much less than that of the distilled water obtained on operating the still for say a few hours a day for a fortnight; otherwise it is better to carry stored water. Simplicity of operation is essential and there must be no complicated mechanism likely to fail in emergency. Further, the equipment must be so designed that large numbers can be made quickly by mass-production methods, with very little skilled labour.

In the first place, several stills were designed to produce from one pint to four pints of drinking water an hour. These stills were made by highly-skilled technicians in the workshop. At the same time, experiments were made in

co-operation with the oil industry and others to select a fuel and a burner to heat the stills. In the next stage, the equipment was used to distill sea-water from the North Sea. It was important that natural sea-water should be used in the experiments because it is more liable to froth and boil over than tap-water in which salt has been dissolved. Tests were then made in the workshop and in the open air under conditions similar to those in a boat at sea. To imitate the tossing of a boat the stills were operated while swinging in a pendulum, and to imitate a strong wind, a current of air from a fan was blown over the equipment. Later, tests were made by several groups of seamen using the stills in life-boats on the sea. Several improvements resulted. During this time the scientists worked in co-operation with firms who might make the stills and burners in large numbers. This is the stage at which the precision model of the research technician is converted to the mass-produced but efficient article.

Two types of still have been chosen for production and a third is under consideration; one type was designed by the Department of Scientific and Industrial Research, and the others were due to individual inventors. Each still produces about four pints of drinking water an hour; and the volume of water obtained when the still is operated for several hours a day for a fortnight is much greater than the volume of the still and fuel. One type of still is heated by an oil burner, and the others are heated by burning briquetted coal, wood, or other solid fuel.

Let us imagine that we are in a life-boat and wish to start up the still heated by oil. This still is in the form of a vertical cylinder with a central flue containing the burner. It is first clamped in position in the boat. Sea-water is poured into a reservoir at the top; this reservoir is like an unspillable inkwell, so that sea-water is not lost when the boat tosses. A turn of a screw opens the oil feed from a tank surrounding the still, to the burner, which is then lit. All that is then necessary is to add sea-water at intervals. After a short

time drinking water flows steadily from a pipe near the base, and continues to flow at four pints an hour so long as the burner is lit.

It is intended that stored drinking water shall continue to be carried in life-boats, and that the fabric rain-catcher and still shall be additional equipment. There should then be no real shortage of drinking water.

I've only told you about one or two of the developments made by scientists to meet the special conditions of war. There have been many other improvements. Though the requirements in times of peace are not so stringent as in war, some of these developments will find their uses also in saving life at sea, when the war is over.

H. S. HUMPHREYS, Chief Engineer Superintendent of the British Tanker Co. Ltd.

When an oil tanker is hit by torpedo or bomb, there is a risk that she may catch fire. If this did happen, oil might escape from the tanks causing the sea around the ship to be enveloped in flames, which would tend to spread with the wind, to leeward, over the surface of the sea.

Of course, everybody has always been concerned to protect our undaunted tanker-men from such hazards and the latest development is a new type steel life-boat designed by the Oil Industry—with the co-operation of the Ministry of War Transport.

A model of the boat was tank-tested at the National Physical Laboratory to obtain the best form, with optimum stability for seakindliness and to ensure the best propelling efficiency. A prototype boat was then built by a boat-building firm on the Clyde.

The first essential requirement is to get the life-boat away from the ship's side and clear of flames quickly and to protect the occupants from fire.

The prototype boat was designed to meet these essentials and to give good sailing qualities and to prevent, so far as practicable, undue exposure and exhaustion of the crew.

It was decided to adopt the open cockpit type of boat 28 feet in length, with a raised steel deck forward and aft.

The buoyancy tanks are built into the boat, forming a double shell.

A deep coaming extends all round the cockpit, which is protected by a fireproof sliding canopy.

Water sprayers, worked by two hand pumps, provide a constant spray of water over the whole external surface of the boat above the waterline.

The new boat can be propelled alternatively by Diesel engine, or electric drive, or Fleming hand-gear.

The hand-gear is operated by eight hand levers linked to the propeller shaft through a gear-box. The electric drive is operated by motor-car batteries.

The sails consist of jib, lug and mizzen.

The life-boat has a capacity for 33 persons, and, when fully manned and equipped, weighs about seven tons.

She is fitted with quick releasing gear and lowered into the water by gravity davits and flexible steel wire falls.

In the fully-loaded condition the ten horse-power Diesel engine produced, in the prototype boat, a mean speed of five and a half knots, that is about six and a third miles an hour. The speed with the hand-gear was four knots which represents about four and two thirds miles an hour.

Sailing trials and tests of the seating arrangements and stability entirely satisfied the Ministry of War Transport surveyors.

The most important test was that which required the boat to be subjected to intense fire and smoke for a period of four minutes; four minutes was laid down for the test because it was estimated that in that time the boat could be propelled, either by power or hand-gear, a distance of at least a quarter of a mile against the wind, guided by a wind indicator; and

a quarter of a mile should take the boat beyond the limit of any oil which might be burning on the sea.

A large water tank, in which the boat was placed, was used for the fire tests. The surface of the water was heavily covered with oil and ignited.

During the final fire test the boat was occupied by personnel who had been concerned with its development. This test was extended to five minutes, during which time the flames reached heights of over forty feet, the boat being lost to view in smoke and flames.

The quenching and cooling effect of the water sprays, on which the safety of the crew and boat depends, was very noticeable. The occupants showed no signs of distress after their ordeal and intimated that conditions within the boat never became unpleasant; neither was the sea-worthiness of the boat nor the efficiency of the fire protection affected.

The Ministry of War Transport have now placed initial orders for 500 of these boats, together with the corresponding sets of gravity davits and equipment and have authorized conversion of existing boats to incorporate the fire-fighting provisions of the new boat, which represent an advance upon the arrangements previously provided.

SCIENCE AND SHIP DESIGN

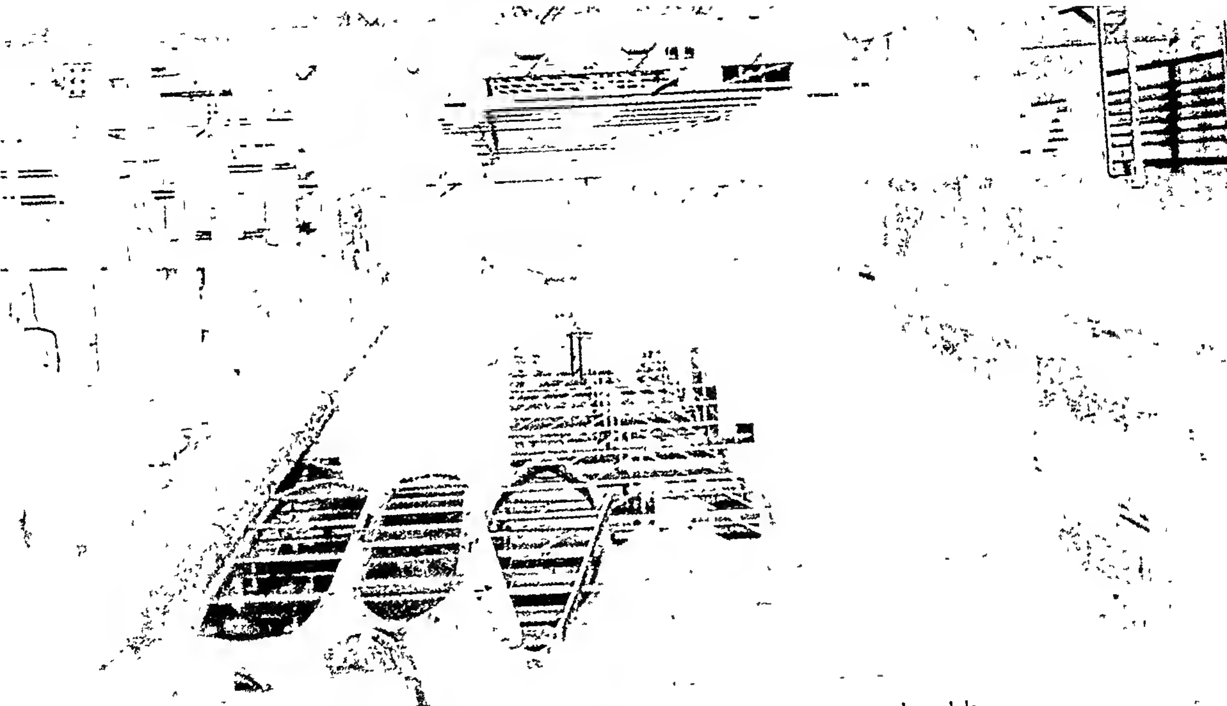
By J. L. Kent, Superintendent of the William Froude Laboratory of the National Physical Laboratory

It is not necessary for me to tell you why we need a first-class Royal Navy, because we've known for many generations past that our very existence as a nation depends upon the efficiency of our warships and the men who man them. But do we need a large and efficient merchant navy? Surely, the various unaccustomed things we do, and do without in this war, in order to save shipping-space, must have taught the most obstinate landsman amongst us our dependence upon ships, ships, and still more ships. A large merchant navy is vital to our existence and the Royal Navy is the policeman who sees that the ships of our mercantile marine can pursue unmolested their lawful business upon all the seven seas.

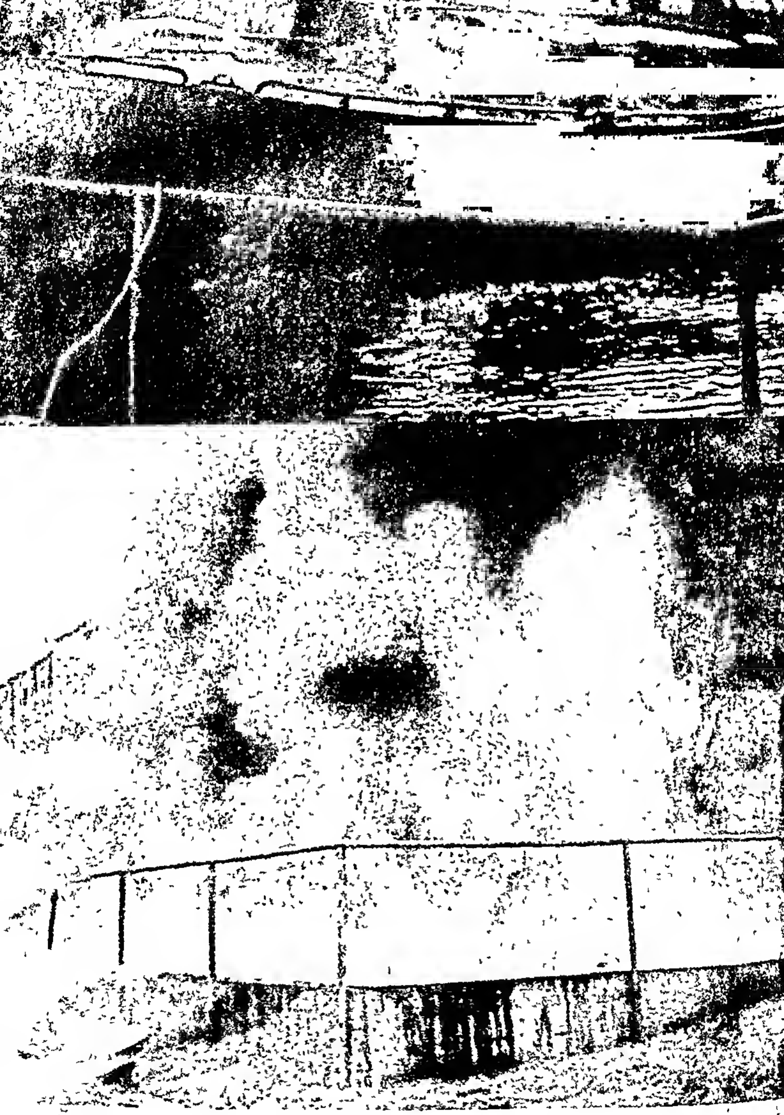
If the merchant navy is to exist in the face of the fierce competition which has attacked it in the past and may again, it must have efficiently designed ships, and the seamen must be efficient at their jobs. To secure such efficiency, science can be used in a multitude of ways in ship design.

The State enforces rules which are meant to ensure the ship's safety at sea, and certain others known as the tonnage laws. These latter are supposed to be a measure of the space available in the vessel for carrying cargo, and it is on this cargo capacity measure, that port, dock and canal dues are levied as a kind of income tax. These laws very greatly affect ship design, and they should have a strong scientific basis. Too often, however, in the past they have been based upon tradition and rule of thumb.

To design a merchant ship successfully, the naval architect



Showing the Alfred Yarrow Tank with the carriage spanning the waterway, and models



Top—New fire-resistant steel life-boat for tankers, showing water sprays being tested before the fire test

Bottom—The life-boat hidden in smoke and flames during the fire tests

uses every branch of science—the mechanical sciences in efficient engine and boiler design and also in hull design where the aim is to combine minimum hull weight with maximum strength and so squeeze a little more cargo-carrying space into the ship to earn more money per voyage. The physical sciences for navigation instruments such as echo sounding apparatus and wireless direction finders, as well as refrigeration or air conditioning of the ship's holds, which in recent years has made possible the sea transport of meat and soft fruits like bananas. The chemical sciences are used in the means taken to reduce corrosion and fouling of the ship's bottom, so increasing the life of the ship and preventing a serious drop in her speed. Even the medical sciences are studied in the lay-out of hospital ships and the sick bays of warships and liners. Mathematics is, of course, greatly used for stability, strength and resistance calculations, some of which are extremely complicated. The science of economics plays its part in the study of trade-route conditions and this has a great influence on the ship dimensions and design. So you see every branch of science must be used if the road to the perfect ship of the future is not to be strewn with costly failures.

Naval architects must have a good working knowledge of all these sciences if they are to succeed, and as may be expected they are, as a class, famous for their humility, for of all the professions, theirs is the one which daily emphasizes the depth of ignorance of the wisest men of the way in which Nature's laws work, and as Solomon put it, the way of the ship upon the sea is still beyond man's understanding.

The purposes for which ships are built are so many and so varied that each class presents its own particular problems for solution and a brief glance at a few of them will, I think, show how science is used to solve these.

Warships may have to carry large heavy guns at high speeds over long distances, work in compact fleets and be capable of offensive action day or night in all weathers

whilst protecting themselves from hostile action of all kinds—bombs, torpedoes, mines and gunfire. To do this the variety of precision instruments of highly scientific design used in such craft is staggering. Submarines and aircraft carriers became practicable ships only after much scientific research on their designs, and such things as the sweeps used by minesweepers to clear the fairways of mines, were only successfully developed after much work by scientists. The war has seen the introduction of many strange looking vessels for amphibious operations, and the design of these assault craft presented many a knotty problem for the scientist to solve. In the merchant navy science ensures the passenger's comfort by giving him an even temperature in his cabin, which must also be free from objectionable noises and odours. These cabins are furnished to minister to the passenger's slightest need, satisfy his aesthetic taste, and all with an economy of space quite phenomenal. On the other hand, the horse-drawn canal barge was the subject of much full-scale scientific research in England over 110 years ago—experiments which have since become a classic in the profession, and even now science is re-shaping our barges. In recent years the resistance of the humble barge has been reduced by over 40 per cent without increase in cost or sacrifice of carrying capacity.

The defenders of the America Cup had the hulls and sails of their yachts scientifically designed and tested in a ship model experiment tank, and the result fully justified the use made of science in their design. Even the racing eight has been the subject of scientific design in order to secure low resistance, light weight and great strength.

To explain how modern science can be harnessed to ship design, let me describe one comparatively small, though highly important part of the work of designing a merchant vessel.

This is finding the most efficient shape of hull for the job required of the vessel, with due regard to cost, safety, capacity,

practicability of construction, dimensions, wharfage and port facilities upon the route on which she runs, and a few other things. The aim must be to secure low resistance to lessen fuel consumption, so the science of hydrodynamics is evoked, and experiments with models bridges the gaps in our scientific knowledge. These experiments are done in model testing tanks, which are like huge swimming baths as wide as a road and about 200 yards long. They may be 10 to 16 feet deep, too, although arrangements are made to make the water shallow and to build up in miniature such waterways as the Suez Canal, or the mouths of some of the great rivers when problems connected with steering in confined waters have to be solved.

A large steel bridge, which may be anything from 5 to 45 tons in weight spans the tank and can be driven at high speeds along it, upon levelled rails fixed to the tank walls. This carriage is used to tow the models and carry the experimenter with the measuring apparatus. The model hull itself is usually made of wax, which is cast in a china clay mould and shaped in a specially designed machine. This machine cuts the correct contours in the wax casting while the operator traces them one by one upon a drawing of the ship design. These wax models, by the way, are not small affairs. They vary in length from 16 to 20 feet and weigh anything from three-quarters of a ton to a ton-and-a-half, and in special cases may reach 4 to 5 tons when fully loaded. I have known as many as three grown men carried in one of these models during special work. When finished, the model is towed through the water at various speeds, its resistance measured and the wave patterns it creates in the water are filmed and studied. This enables the naval architect to see whether the ship will get the desired speed economically and if not, his experience and training suggest changes in hull form, which are rapidly made on the model and tested. The propeller is designed on scientific principles and a model screw made and fitted to the hull. Further experiments are

carried out with the model propelling itself at various speeds down the tank and from the data so gathered, the engine power, screw revolutions and efficiency are obtained. In the last fifteen years such tests have resulted in a 20 per cent reduction of the fuel bill of the modern cargo ship and has literally saved hundreds of thousands of tons of fuel. These experiments may be followed by such tests as steering to prove the rudder, or rolling to examine the efficiency of the proposed bilge keels. Or waves may be created in the tank by a special machine and rough water experiments carried out, when the pitching and heaving of the model are automatically recorded, the aim being to reduce the unpleasant erratic ship motions in storms and so save fuel and the passengers' appetites. These large experiment tanks are also used in war-time to perfect many ideas concerning things put into the sea to annoy enemy shipping, and to protect our own merchant and royal navies.

In addition to these large experiment tanks water tunnels are also used for the scientific study of propeller action under a heavy thrust—as in destroyers, say, where many thousands of horse-power are absorbed by each screw. These tunnels are very like the now famous wind tunnels used in the study of aeroplanes in flight, with the difference that water is pumped through the tunnel instead of air.

Yet another adjunct of the experimental tank is the steering pond in which large-scale models turn circles under their own power and record the efficiency of the proposed rudder design together with the power required to operate the steering gear.

When economic conditions rapidly change, as during slumps or booms in world trade, cargo ships hitherto very efficient, suddenly become uneconomical because their dimensions and the cargo capacity of their holds are unsuited to the new conditions. Then ship surgery is the only cure and an operation is performed on the hull. The ship is cut in two, and whole sections of it removed or new holds

are built in as science dictates. Where the ship is to be cut, and the exact amount to be added or removed from her hull, is decided by careful scientific experiments in the ship model tank. Not so long ago a whole class of low power cargo ships trading to the Orient were shortened and some high power liners lengthened, so as to remain paying propositions in spite of drastic changes in world trade, and science once again proved its use to the business world. Experiments on ship models are followed by tests in the actual ship on her acceptance trials and maiden voyage. Then the scientists endure all the discomforts of sea and weather (and often internal uneasiness, too, as I know from experience) to secure facts which will shed light on obscure points of design. I recall one such case in the *Berengaria*. Her bridge was over 100 feet above the water, yet spray continually drenched the bridge deck. By studying the movement of snowflakes during a snow flurry this was shown to be due to an unpleasantly shaped bow wave far below, and was demonstrated by holding a length of rope over this wave with the vessel doing 23 knots. When let go the rope soared skywards up the tiers of decks and landed upon the bridge. This wave was entirely due to the ship lines and because of the expense nothing much could be done to alter it. But in subsequent vessels care was taken to avoid the creation of such waves. On another voyage for an hour during a violent storm in the Caribbean sea I was suspended at the end of a rope over the stern of a large tanker (which was performing dizzy and erratic gyrations at the time), in order to secure a photograph of the action of the rudder in a seaway, and this information gave facts which were used in future rudder design.

Now is the expenditure of all this effort, expense and time on the scientific design of a tramp steamer say, really necessary and a matter of national importance? By taking all this care, the cost of transport by ship of goods from abroad can be cheapened. With intensive scientifically directed

research, goods hitherto not generally obtainable in this country could be transported cheaply and without damage from the countries where they are made or grown. The war has shown us that if we were reduced to the bare essentials to support life, civilization would take a long stride backwards. It is not too much to say that progress in civilization depends mainly upon an abundant stream of the ornamentals of life such as art in all its forms (painting, music, literature, and so on) including those unessentials of life which please the five senses, as for example, tropical fruits and flowers, scents and such things as tea, sugar and spices, rubber and so on which can only be obtained abroad. These can be made available to all to raise our standard of living, if we possess a cheap, plentiful and efficient sea transport, for science teaches that the cost per ton of cargo by air transport will always be many times that of water transport, if both services are economically independent and run without subsidy.

The ordinary man-in-the-street and especially his housewife, will benefit directly from a large fleet of scientifically designed and operated merchant ships. Cheap transport leads to cheaper goods in greater variety, which permits the housewife greater choice in the exercise of her aesthetic instincts and desires, when selecting her purchases, and so raises her family's standard of living.

For many centuries the design of ships was an art, and success depended upon the personal skill of the naval architect and the craftsman who built those ships. With the march of civilization this art is fast becoming a science and to enable the naval architect to design better and better ships, science must be increasingly used. This can only be done successfully if research is carried on unceasingly.

THE TUNNEL BUILDERS

By G. L. Groves, B.Sc., M.Inst.C.E.

The work of the tunnel builder is not only *at* your service, it is *in* your service, day and night, year in, year out. For civil engineering works are the bed-rock of our national life. And tunnels, together with roads and railways, bridges, docks and such like, make up an equipment—a sort of national tool-kit—without which our way of living would be completely upset.

Supposing, for instance, that, by some malevolent agency, all the tunnels in this country were put out of action, what sort of plight should we be in? To take the most obvious thing first, long-distance traffic on the main line railways would come to a standstill because the railway systems would be, for the most part, cut up into short, isolated lengths; and all London's tube services would cease to run. That would be bad enough for those of us who have much travelling to do. But far more serious would be the interruption of supplies —food, coal, munitions, and many other things that are more than ever vital to us nowadays. That, however, is by no means the complete picture. You who live in several of our larger towns and cities would lose most, if not all, of your water supplies, because they are brought to you from distant reservoirs by aqueducts which, in parts of their lengths are tunnels. (Big tunnels they are, too; a lorry could be driven through some of them if they were empty of water.) Another calamity would be the stopping up of sewage systems in scores of towns up and down the country; in most large centres of population parts, at least, of these systems will have been constructed by tunnelling. (I wonder if Londoners realize that there are upwards of 400 miles of

main sewers alone in the vast drainage network of their city.) Again, there would be failure of electric supplies from those great power stations—and there are quite a few—in which the condensing water essential to the operation of modern turbine plant is circulated through tunnels.

Well, that is a dismal list of disasters. I could add to it, but you can see clearly enough how many necessary services, which we take pretty much for granted, owe something to the skill of the tunnel builder.

It was in the early part of last century that tunnelling began to develop scientifically as a branch of civil engineering practice. Two things happened then which are landmarks in tunnelling history—the invention of the tunnel shield and the construction of the Thames Tunnel.

I'll come to tunnel shields in a minute. Before doing so, let me tell you briefly of the fearful difficulties which had to be faced by the first engineer to link the two sides of London's river by tunnel. It is the first chapter of a story which is still being written—the story of big tunnels under wide rivers. Some important chapters are likely to be added to that story in the years to come.

In 1835, Marc Isambard Brunel started to build a tunnel under the Thames between Wapping on the north bank and Rotherhithe on the south. It was an ambitious undertaking for those times, for not only had nothing of the kind been attempted before, but the tunnel was to be of great size. It was to have a double roadway in one rectangular brick-work structure measuring nearly 40 feet in width and over 20 feet in height. The boldness of the project created a sensation, not only in this country, but abroad. The Duke of Wellington, referring to this, said, "I speak from my own knowledge when I state that there is no subject with reference to which the interest of foreign nations is more excited than the tunnel under the Thames; they look upon it as the greatest work of art ever contemplated."

But Brunel found himself in difficulties almost from the

start. The clay through which he expected to drive the tunnel turned out to be mingled with seams and pockets of water-bearing gravel, and with silt of a particularly unwholesome nature—unwholesome because the Thames was then London's main drain. This was a grievous set-back for Brunel and his work resolved itself into one long fight against the threat of the river to break in. Often the river did break in, twice so violently that it swept the workmen off their feet and flooded the part of the tunnel already completed. The second time this happened six were drowned and Brunel's son—later to become engineer to the Great Western Railway—narrowly escaped with his life. The workmen fell sick; they came out on strike; fire-damp added another anxiety; money ran short as the time spent on the work grew long. In 1829 the works were closed down for nearly seven years. When they were re-opened, with improved equipment, matters went a little more smoothly, although Brunel's untiring devotion to his task never lessened. Before the tunnel had been started he had moved from Chelsea to Blackfriars in order to be near his work; now, for the next four years, he had samples of ground from the working face of the tunnel submitted to him for examination every two hours, day and night. By night, if he was not in the tunnel, the samples were hauled up to his bedroom window in a basket. At last, in 1843—just one hundred years ago—the work was finished. A tunnel scarcely a quarter of a mile in length had taken eighteen years to build at a cost of eleven hundred and forty pounds for every yard of its length. It never served its intended purpose as a vehicular tunnel, for the sloping approaches were not constructed; but foot passengers used it for a time. Then, in 1866, it was incorporated in the East London Railway; now it forms part of London's Underground. Brunel's great work was, financially, a failure; as an example of sustained, dogged courage in the face of almost overwhelming odds it is a triumph. But, above all, it pioneered the approach to a new field of enterprise.

The civil engineer has to tunnel through all kinds of ground, from running sand to material which needs explosives to break it out. More often than not he has to deal with ground which is not self-supporting, which means that the tunnel must be provided with a permanent lining, or it would fall in.

In soft or loose ground it is the aim of the tunnel builder to get this permanent lining erected as early as possible. But the surrounding ground may not oblige him by waiting for him to build his permanent lining, however speedy he may be. So *temporary* support has to be provided to hold up the ground until the permanent lining can be built. Timbering was almost always used for this temporary support in the old days; (it is by no means out of use to-day). But the timbers have to be set up afresh for every short step forward and much time and labour are spent in doing so; a good deal of timber may be wasted, too. Now it occurred to Brunel, before he started the Thames Tunnel, that this repeated work of timbering could be avoided if the ground were given temporary support by a strong, movable framework which could be pushed forward bodily, every so often, as the driving of the tunnel progressed. There you have the principle of the tunnel shield. Brunel used his invention in the great work I have already told you about, but his practical interpretation of it was clumsy and not altogether successful. Its later development, however, has made tunnel construction in soft and loose ground much simpler and much cheaper than is possible with the old-fashioned method of timbering.

We have to thank James Greathead, more than any other man, for the tunnel shield as we know it to-day. Essentially, it consists of a steel cylinder, stiffened internally, and of a diameter slightly larger than the outside of the permanent lining of the tunnel. About half-way along the length of this steel cylinder powerful hydraulic jacks are fitted. These jacks are for pushing the whole shield forward a short

distance—each "shove" is generally about 2 feet—as often as the miners have dug out enough ground at its front end to ease its progress. (You will understand from this that the shield is *not* an excavating machine—it is *merely a travelling* support for the ground outside the tunnel.) After every forward "shove," another short length of the permanent lining is erected *inside* the back end of the steel cylinder of the shield. Thus, the tail of the shield is continually sliding forward over the last length of permanent lining built under its protection, but it always overlaps the permanent lining by some amount.

If you've been able to follow this description of how a tunnel shield operates you may ask "What about the small space left between the outside of the permanent lining and the surrounding ground—the space of about two inches left behind by the skin of the shield as it slides forward? Is this space allowed to fill up naturally in course of time?" No, it is not; the result of such a thing might be settlement of the ground above the tunnel and damage to property on the surface. So the space is filled with liquid cement, forced in under pressure, each time the shield is moved. This cement soon sets as hard as stone.

Nearly all the tube railways in London, and scores of tunnels for all kinds of purposes in various parts of the world have been driven with the help of shields of the Greathead type. (Incidentally, mention of tube railways prompts me to point out that the longest railway tunnel in the world is *not* the Simplon with its 12½ miles, but London's Northern Line, on the Underground. From a point near Morden in the south to where it again emerges into the open near Golders Green in the north, this tube railway is in tunnel for a distance of just over 20 miles.)

Another powerful weapon in the tunnel engineer's armoury is the use of compressed air. Tunnels have frequently to be driven in water-bearing ground. By shutting off the tunnel workings from the outside air and raising the pressure of

the air within them, the water in the ground can be kept out and the work of driving the tunnel carried through in the dry. The pressure required depends on the level, relative to the tunnel, of the source of the water which would otherwise cause flooding; but there is a limit to the pressure that can be used. With increase of pressure there is increased risk of compressed-air sickness; this is painful and sometimes dangerous, and tunnel miners know it as "the bends." It is caused by bubbles of nitrogen which, at the time of decompression (that is, when emerging from compressed-air) may be released from the blood just as bubbles of gas are released from a "fizzy" drink when it is uncorked—though on a much smaller scale. If these released bubbles of nitrogen do not get dispersed, but lodge in the blood vessels or tissues, trouble results. All concerned with compressed-air work are under a great debt to those doctors and others who, by experimenting on themselves under trying and even risky conditions, have discovered the causes of compressed-air sickness and shown what to do to prevent or relieve it. In practice a pressure of 40 to 45 pounds to the square inch above atmospheric pressure is about as high as you can go. (By the way, if ever you should enter compressed air don't expect to whistle. You can't.)

It seems ludicrous to think of railway tunnels as death-traps; but some of our forefathers did. Before the older Brunel had finished his difficult venture under the Thames, his son had completed the Box Tunnel (then the longest in Britain) on the main line between London and Bath. Its two miles were terrifying—too terrifying for many passengers to face—they preferred to break their train journey short of the tunnel, take a coach, drive the next two or three miles and rejoin the railway beyond. Perhaps their fears had been increased by an opponent of the railway company's plan to build the line. He had publicly expressed the opinion that "the monstrous, extraordinary, most dangerous and impracticable tunnel at Box would cause the wholesale

destruction of human life." In spite of this gloomy forecast, the Box Tunnel is, like many other of the younger Brunel's works, still in service.

The most notable work of tunnel construction in this country in recent years is the Mersey Tunnel, which gives vehicular traffic direct connection between Liverpool and Birkenhead. Its main under-river section has an internal diameter of 44 feet and provides accommodation for four lines of traffic on a roadway 36 feet wide. At its lowest point the roadway is 148 feet below high water level in the river above. The length of the main tunnel—there is a branch entrance as well on each side of the river—is two miles. In the first twelve months of operation it was used by more than three million vehicles and the numbers were increasing each year up to the outbreak of war.

The traffic for which the Mersey Tunnel was designed to cater is, for the most part, motor-driven—a factor which increases the cost of modern underground roadways, for the exhaust gases from internal-combustion engines are, as you know, poisonous, and the provision of sufficient ventilation to prevent harmful concentrations of these gases is no small item in the bill. Of the total cost of constructing the Mersey Tunnel (about five and a half million pounds), ventilation accounted for approximately one million.

A road tunnel sometimes offers the solution of a traffic problem when no other satisfactory answer can be found. And that suggests the question: Are tunnels for road traffic desirable only when nothing else would really meet the case? Or, is it better to send traffic underground than to provide new surface roads or to widen existing ones, other things, including cost, being equal? (I am, of course, speaking of congested, built-up areas—nobody I imagine would want to burrow under open country!) But the same questions arise when it comes to choosing between a bridge and a tunnel for a wide river crossing. What would be your verdict

then? These matters raise major issues of policy and planning as well as individual preferences.

Of tunnelling work carried out in connection with the war you will not expect me to speak in detail, although I could tell you a good deal. But tunnels have contributed much to our security by providing protection for all manner of people and all kinds of things in all sorts of places.

It is a far cry from the Thames Tunnel of 1843 to the Mersey Tunnel of 1934 and there has been a revolution in the technique of tunnelling during that period of nearly a century. Mechanical engineers, geologists, and those research workers who have studied the cause and prevention *of compressed-air sickness have contributed to this.* They have helped to apply tunnel construction increasingly to the creation of much that is essentially in our daily lives, with the result that it is now one of the most important means by which the civil engineer is privileged to serve his fellows.

SCIENCE IN NATIONAL LIFE

By E. C. BULLARD, F.R.S.

WHEN one listens to a talk about a particular application of science, to explosives, to textiles, to shipbuilding, or to some other practical subject, it is easy enough to see that the things talked about are interesting and important, but it is not so easy to see that they do not come about by chance because someone happens to have a bright idea. In this talk, the last of the series, I want to try to show that they come from the application of that great body of knowledge collected in the past 300 years and called "physical science."

Now what is physical science? It is the study of the behaviour of inanimate matter. The motion of the planets, the design of a steam engine, the production of petrol, the breaking of a wave on the seashore, the colours of dyes, and the interior of an atom, are all parts of physical science.

Such things may be studied for two reasons. We may study them because they are interesting, and we like to see the connections between apparently widely different things without any ulterior motive, or we may study them to achieve some practical end. The first is called "pure" science and the second "applied" science. Pure science is, I suppose, closely connected with the small boy's desire to take his father's watch to pieces. He does not, unless he is unusually optimistic, expect that the watch will go any better after he has taken it to pieces, he simple wants to see how the wheels go round, and to understand how it works.

The experiments made a hundred years ago by Ampère and Faraday to find out if there is any connection between electric currents and magnetism are an example of this kind of science without practical motives. Applied science

on the other hand is based on an interest in solving some practical problem, such as how to design a better electric motor for a vacuum cleaner, or how to make sea-water drinkable.

Now it is obvious that you can't design a new motor without knowing a good deal about electric currents and magnets, and that the designer of the first electric motor could not have started unless he knew a good deal about them. No one could have said 150 years ago that magnets had anything to do with providing power for sweeping carpets, or making telephones or indeed that they were of any practical use at all, except for picking up pins and making ship's compasses.

Ampère and Faraday showed that a wire carrying an electric current would move a magnet, and that moving a magnet near a wire would make a current flow in it. It is on these discoveries that the electrical industry is based.

The development of electric power and light at the end of the last century and of the immense industry that has grown up round it were absolutely dependent on these discoveries of Ampère and Faraday. Of course, if they had not made them someone else would have made them, but until they were made electric motors could not have been designed. The electric motor could never have been discovered accidentally, or by a sudden bright idea by someone who usually made steam engines. It could only be invented after someone had found the fundamental laws of electricity and magnetism. Until these laws were found it was not clear that they would be of any use, or in fact that they existed. I do not think that they could have been discovered from any other motive than pure curiosity about how nature works.

It is at first sight rather odd that a very practical matter like the electrical industry should be built on such unpromising foundations. Such a connection is, however, very common, in fact, almost universal. If you want to solve some practical problem you can usually only do it if you know

where and how to start looking for the solution, and in any but the simplest problems you can only tell where to start looking if someone has done a lot of spade work first. There are many examples—the wireless valve couldn't be invented till someone had studied the behaviour of the electrons given off by white hot metals in a vacuum—but when, 40 years ago, J. J. Thomson and his students were making the fundamental experiments on these things, they can have had no knowledge of the direction in which their discoveries would be applied, though they may very well have felt that such advances in pure science would bear practical fruit eventually.

I came across another rather topical example recently. I was talking to an astronomer who had become interested in explosives, and I said: "Well, anyway you are having a holiday from stars." "Oh, I don't know," he replied. "I find the work I've done on variable stars comes in very useful; after all, an explosive just after it has gone off is only a mass of hot gas, and so is a star—the theory is very much the same for both."

This solving of a problem by seeing its connections with more familiar things is at the root of much applied science; but such a connection is only useful if we know something about the more familiar thing with which our problem is connected. It is not helpful to say that an explosion is in some ways like a star, unless you know a good deal about stars.

I hope I have said enough to show the justification of pure science from a practical point of view. The first essential for a harvest of useful discoveries and inventions is a continual sowing of the seed of pure research. Pure research has largely stopped now, owing to the war. If it were not restarted there would be little immediate effect, but the practical discoveries of twenty years hence would have been cut off at their source.

The time required for a discovery in pure science to be

applied is longer than one might expect. It is ordinarily twenty to fifty years. The fundamental electrical discoveries which I mentioned just now were made between 1820 and 1835, but it was not until the eighties that the streets of London began to be lit by electricity. Again, Clark Maxwell—the first professor of physics at Cambridge—perfected the theory of electro-magnetism and predicted the existence of wireless waves in 1865 and Hertz first produced them in 1888, but practical wireless telegraphy did not come till 1900, or television and radio-location till the late thirties. The electron was discovered in 1896 but wireless valves were of no practical importance till 1915.

These time intervals are so long that there is, generally speaking, no possibility of making pure research pay for itself. The practical gains come from the fusing of the work of different men over many years into a coherent picture of how things work, most of the items being of no special value by themselves. The engineer who designs a ship uses a knowledge of the mechanics of water. This knowledge has been accumulated gradually during 250 years from the time of Newton to the present, or perhaps I should say during the 2,000 years since the time when Archimedes had *his* bright ideas while sitting in his bath in Syracuse. Clearly the men who accumulated this knowledge could not have made a living or have paid for their experiments directly by selling such knowledge from year to year as it was acquired. We therefore see that pure research, although essential for practical ends is not self-supporting, and how it is that pure science, although one of the best investments that a country can make, is at the same time perpetually short of money. The trouble is that it is, as business investments go, a little slow in maturing, and also that the financial benefits cannot usually come directly to those practising or supporting it. Copernicus could not patent the discovery of the motion of the earth round the sun, nor could Newton sell the law of gravitation, yet, in the long run, their work was immensely

valuable. It enabled more accurate predictions to be made of the positions of the sun, moon and stars, and thus made the navigation of ships more certain. Once the motions of the heavenly bodies were understood it became a matter of applied science to make the best use of this knowledge, and this applied knowledge was saleable. During the eighteenth century a much increased demand for instruments for navigation grew up, based on the new methods and depending on the astronomical discoveries of the two preceding centuries. The government offered a £20,000 prize for a clock that would keep time on board a ship and firms of instrument-makers set up in business to supply this and other wants of sailors. As some of these firms still exist we may suppose that they have found the making of sextants and chronometers profitable.

From this one would expect that pure science would only flourish in a fairly prosperous country. In a country, that is, that can afford to lay aside a certain proportion of its resources each year, and use it for work that will not bear fruit for a number of years, and much of which will never be of any use at all. Until recently this laying aside was done largely through private benefactions to universities. However, as the simpler parts of science get worked out and attention is directed to more and more deeply-lying parts, the complexity of the equipment required gets greater and the cost increases. The giant telescope that is to be erected on Mount Palomar in California will cost over £1,000,000, and the atom-splitting cyclotron at the California Institute of Technology cost several hundred thousand pounds. These are sums that are, except in occasional instances, quite beyond the reach of private benefactions, and progress in science has come to depend more and more on government grants derived from taxation. It seems likely that if this country is to keep up with the startling developments in the United States and in Russia this process will have to go farther still. This raises difficult questions of how to retain the traditional

and necessary freedom and independence in the development of science, and at the same time secure efficient administration in the spending of large sums of public money. I will leave it to you to discuss this in detail. I must return to my main theme, the relations between pure and applied science.

I have spoken of the contribution of pure science to practical affairs and to industrial development, now I want to talk about the reverse connection. Most advances in pure science depend on new methods of doing things and these new methods are provided by advances in applied science. There is thus a kind of alternation between pure and applied science, each depending on the other for its advances. For example, a hundred years ago the simplest electrical experiments were very difficult to carry out, because of the absence of elementary requirements like electric wire. Faraday, in his diary, describes how he wound his magnets with milliners' iron wire which was, and for all I know still is, used for stiffening ladies' hats. The insulation was provided by winding string between the turns of wire. As I have explained, these experiments of Faraday's led in the course of 50 years to the electrical industry. With the development of that industry things like insulated wire, magnets, dynamos, motors and accumulators became commonplace, to be bought in a shop. This immeasurably simplified all experiments involving electricity, and rendered possible the fundamental researches of J. J. Thomson, and others, which led to the discovery of the electron. These experiments in turn led to the invention of the wireless valve, which has itself laid the foundations of the great and expanding radio industry—and to my talk to-night. This industry has made valves a commonplace in the same way that earlier electric developments provided lamps and motors for all. This plentiful supply of valves has made possible the experiments of the last fifteen years on the structure of the atom and has led to an enormous increase in our knowledge of how atoms work.

It is quite possible that this knowledge will find some quite unexpected application and be the key to the growth of some industry, which will in its turn make easier a new attack on yet more fundamental properties of matter.

I now come back to where I started. The practical advances about which the other speakers in this series have talked do not come by chance because someone happens to have a bright idea. The bright ideas must be there, but no one can have them without a background of knowledge collected by others. No one can start having ideas about, shall we say, how to make better dyes until they know what sorts of arrangements of atoms give coloured compounds and what happens if you add a nitrogen atom here or a carbon atom there to the dye molecule. I happen to have chosen the chemistry of dyes as an example; but this point was well brought out in earlier talks on Plastics and Explosives.

There is just one other thing: the development of science requires not only the right men, but also the right circumstances, and given the right circumstances the men will usually appear. Both in pure and in applied science you need not only the individual genius, the Newton, the Faraday, or the Rutherford, but also the right surrounding circumstances. For such advances a country must be rich enough to make an investment that will not show a profit for many years. For such advances a country must be large enough to provide an adequate supply of rank and file scientists as well as a few great men. It must be sufficiently industrialized to provide the means, and to some extent the incentive for advances. Without all these neither pure nor applied science will flourish. We can see this if we consider why this country, the United States, and Germany have during the last fifty years contributed such a large proportion of the world's scientific progress, and countries such as Spain and China have so far contributed relatively little.

A scientific discovery is not a thing in itself which develops

separately from the rest of the life of the country, it depends very intimately on the wants and habits of ordinary people, on the kind of government they have, and on the educational and financial system they support or tolerate. We are no more intelligent than our ancestors, but we have learnt more about nature in fifty years than was learnt in the first 1,500 years of our era. To state precisely what are the conditions for a healthy development of science is a difficult thing: the conditions that give that combination of curiosity, self-confidence and patience that make a scientist are subtle and elusive, but it is at least certain that practical discoveries do not happen of themselves, they depend on threads running right through the fabric of the country's life.

THE END